EM-63 Decay Curve Analysis for UXO Discrimination
ESTCP Contract # 200035
Final Report

NAEVA Geophysics

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1 Introduction

1.1 Background Information

The Department of Defense (DoD) is currently involved in a number of UXO site remediation efforts where rapid transition of advanced technologies can save substantial sums of money and significantly expedite the transfer of lands for re-use. One of the most prominent of these efforts is the ongoing UXO cleanup of the Kaho'olawe bombing ranges. The major difficulty with this site is that the significant magnetic anomalies from geologic sources and near-surface fragments make traditional magnetometer-based surveys impractical. Standard EM-61 metal detection surveys have also performed poorly in these conditions, due to the very high magnetic susceptibility response of basalt and basaltic soils. As of 1 March 2000, contractors at Kaho'olawe had detected 12,121 subsurface anomalies, and after digging, they found that only 4 percent are UXO, 32 percent are false positives due to geologic variations, and 64 percent are due to buried metal from both UXO and non-UXO-related materials ("The Parsons-UXB Express", Volume 2, Issue 3, 16 March 00, Ref. 2). The focus of this project is to evaluate, under more realistic conditions, the Geonics EM-63 multi-gate time domain metal detector, in order to quantify its detection, discrimination, cost, and production rates while operating at several locations within Jefferson Proving Ground (JPG) that contain varying degrees of magnetic noise levels. Following in-depth evaluation of performance at the JPG site, ESTCP plans to transition the most promising technologies to Kaho'olawe for additional demonstrations at controlled and live sites during FY01. This project was designed to incorporate the lessons learned from previous UXO technology demonstrations and to extend the results of the JPG Phase IV Demonstrations that were completed during FY 97. The JPG IV results indicated that advanced UXO sensing and processing technologies have the potential to significantly reduce the number of false alarms. Unfortunately, those demonstrations incorporated a number of artificial factors that limited the validity of the conclusions that could be determined from the results. Some of the artificialities included the use of non-realistic clutter items, the fact that all of the clutter items were made available to the demonstrators for system training prior to the field tests, and the lack of wide area search requirements. In addition, JPG Phase IV demonstrations did not provide the operational performance data required to quantify the cost savings and risks associated with using these technologies in actual cleanup operations. (Referenced from "Advanced UXO Detection/Discrimination Technology Demonstration – U.S. Army Jefferson Proving Ground, Madison, Indiana", 2nd Draft, 15 April 01)

1.2 Official DoD Requirement Statement(s)

This project addresses the Tri-Service Environmental Quality Research, Development, Test and Evaluation Strategic Plan UXO requirements and, more specifically, the Army requirement A(1.6a), titled: Unexploded Ordnance (UXO) Screening, Detection, and Discrimination and described the FY99 Army Environmental Requirements and Technology Assessments (AERTA). This Army requirement has been ranked as the highest priority user need in the Environmental Cleanup Pillar. In addition, this project addresses the UXO detection and discrimination requirements and recommendations described in the Defense Science Board Task Force Final Report on UXO Clearance and Remediation published in 1998 and provides information needed to develop more accurate estimates of the overall DoD UXO environmental remediation costs.

1.3 Objectives of the Demonstration

The overall technical objective of this demonstration was to evaluate the detection and discrimination capabilities (including production rates and costs) of the Geonics EM-63 multi-time gate electromagnetic metal detector, and associated decay curve matching algorithms in realistic clutter environments and difficult magnetic basalt sites such as Kaho'olawe, Hawaii. Three test grids within JPG were prepared to represent a range of conditions, in order to identify relative strengths and weaknesses.

The evaluation objectives for the JPG controlled site demonstration of the EM-63 (and the other two systems) were:

a) To evaluate detection and discrimination capabilities by means of the three one hectare surveys at JPG under realistic target/clutter scenarios, and while operating efficiently to minimize time and costs.
b) To evaluate ability to analyze data on-site (NAEVA-GPA did not have on-site processing) and provide prioritized target lists.
c) To collect manpower, time, productivity, and cost data for all data acquisition and processing tasks.
d) To compare the performance of the Geonics EM-63 and other advanced, demonstrated technologies with the base-line 'magnetic gradiometer and flag' technology.
e) To provide quality, geo-referenced data for post-demonstration (off-site) analysis, development of ROC curves, and for use by other Government, university, and industry researchers to develop improved analysis technologies.

1.4 Regulatory Issues

There were no regulatory issues in connection with NAEVA's ESTCP demonstration performance at JPG. The primary regulatory issue, which will affect the adoption of discrimination technology such as EM-63, will be gaining the confidence and approval of Federal, State, and local regulators, stakeholders, and users. Acceptance by organizations such as the Army Corps of Engineers and Naval Facilities and Engineering Command will be needed in order that future RFP's will include such innovative technology. This controlled site ESTCP demonstration (JPG-2000) is the first to employ realistic conditions, which will allow side-by-side comparisons of discrimination performance, production rates, and costs. Acceptance of discrimination technology (that is, not digging some of a prioritized geophysical target list) ultimately requires a cost/risk evaluation by the regulatory agencies.

1.5 Previous Tests of Geonics EM-63 Technology

NAEVA Geophysics demonstrated the use of the Geonics Protem time domain EM system for UXO discrimination at the Advanced UXO Detection/Discrimination Technology Demonstration at the Jefferson Proving Ground (JPG) in 1998. This system was the prototype for the new EM-63 multi-time gate system that became available late in 1999. NAEVA was selected to

demonstrate the EM-63 discrimination capability, for JPG in 2000, using algorithms and software developed by G. Hunter Ware, Hunter A. Ware, and William F. Tompkins, of Geophysical Associates (GPA). This also entailed development of GPS integration software, which was accomplished for the Blossom Point, Md., EM-63 tests in May-June, 2000.

2 Geonics EM-63, Technology Description

2.1 Description

The EM-63 Metal Detector, manufactured by Geonics, Limited of Toronto, Canada, generates a pulsed (time domain) primary magnetic field (using a horizontal, multi-turn, air cored, 1m x 1m transmitter coil 40 cm above the ground surface) which induces Faraday eddy currents and magnetic polarization in nearby metallic and/or ferromagnetic objects. The decay of the resulting secondary magnetic fields over time is detected in receiver coils 40 cm (bottom coil) and 80 cm above the ground (co-axial with the transmitter coil). The observed decay as a function of time is determined by the character of the target object (size, shape, orientation, and composition). In general, the observed decay is a linear superposition of the axial (longitudinal) and transverse excitation responses of the target object.

The transmitter current waveform is bipolar rectangular with 25% duty cycle, 15 amps maximum. The EM bottom sensor coil is a circular 50 cm diameter multiturn air cored coil, co-planar with the transmitter coil, with 500 kHz bandwidth. The top sensor coil is a 1m x 1m square coil 40 cm above the bottom coil and transmitter coil (identical to the EM-61 top coil). Twenty to thirty geometrically spaced time gates are measured, covering a range from 180 micro seconds to 20 milliseconds (medium base frequency) or 180 microseconds to 7 milliseconds (high base frequency).
The system controller is a PRO4000 field computer (486 AMD processor), the DAQ dynamic range is 18 bits. Acquisition speed is 6 records (25 time gates per record) per second.

2.2 Strengths, Advantages, Weaknesses

The EM-63 multi-channel (multi-time gate) information permits discrimination of various metallic objects with different sizes, shapes, compositions, and orientations (and may also discriminate basaltic materials from metallic objects), using the shape of the time decay response across the instrument’s 20 – 30 time gates.

Time decay curve shape analysis permits the recognition of specific ordnance items that have been bench tested and cataloged in a database. It does not permit generic discrimination of ordnance from non-ordnance by class. Some non-ordnance items may, by chance, exhibit decay curves, which match certain ordnance items. Therefore, the list of ordnance items to be recognized should be restricted to those actually expected on each particular remediation site.

2.3 Factors Influencing Cost and Performance

The EM-63 is not very different in size, weight, or footprint, from the conventional EM-61 metal detector, and is operated in a similar way by a one or two person field team. Data acquisition costs are therefore expected to be comparable. Data processing is similar, except that there are more channels to be leveled, lag corrected, edited, and analyzed for target picking. Data analysis costs will be somewhat greater, due to the additional chi-squared discrimination step (in order to prioritize the target list). This additional data processing is not expected to cost more than 50% more, once standardized software is completed.

3 Jefferson Proving Ground, Site Description

3.1 Background

The Jefferson Proving Ground (JPG) is located near Madison in southeastern Indiana. JPG covers more than 22,000 hectares (55,000 acres) and includes impact areas, buildings and other infrastructure. The year 2000 Advanced UXO Detection/Discrimination Technology Demonstrations took place at three one hectare test grids within the areas designated in previous JPG technology demonstrations as the 40 acre/16 hectare site and the WES test site. These sites are located in the northeast part of JPG, in land characterized as uplands containing grass and scattered trees, with residual and transported clayey soils developed upon Paleozoic (Silurian) flat-lying shales, limestones, and dolomites.

3.2 Site/Facility Characteristics

Inert UXO and natural and manmade clutter items were emplaced at the three controlled grids at JPG for demonstrators to test their detection and discrimination capabilities under realistic conditions, and allow the Government to estimate production and cost rates in actual cleanup operations. The three one hectare test grids were chosen, to provide grids characterized as relatively ‘low’ ‘medium’ and ‘high’ magnetic clutter (from geologic sources). Figure 1 illustrates the locations of these three demonstration grids within the JPG 16-hectare (40 acre) and WES test sites. Grid 1 contains an elongate ‘high’ magnetic anomaly (+150 nT to – 100 nT), and was seeded with the largest concentration of inert UXO targets and clutter items. Grid 2 exhibits a more ‘moderate’ magnetic response (0 to 35 nT) and irregular topography. Grid 3 contained very low magnetic terrain response, and very flat topographic relief. It was seeded with the fewest targets and clutter items. It should be noted that all of these grids are presumably low magnetic relief compared to Hawaiian basaltic terrains, which are normally +/- many <u>thousands</u> of nT due to the very high magnetic susceptibilities and magnetic inhomogeneity of basalt and basaltic soils.

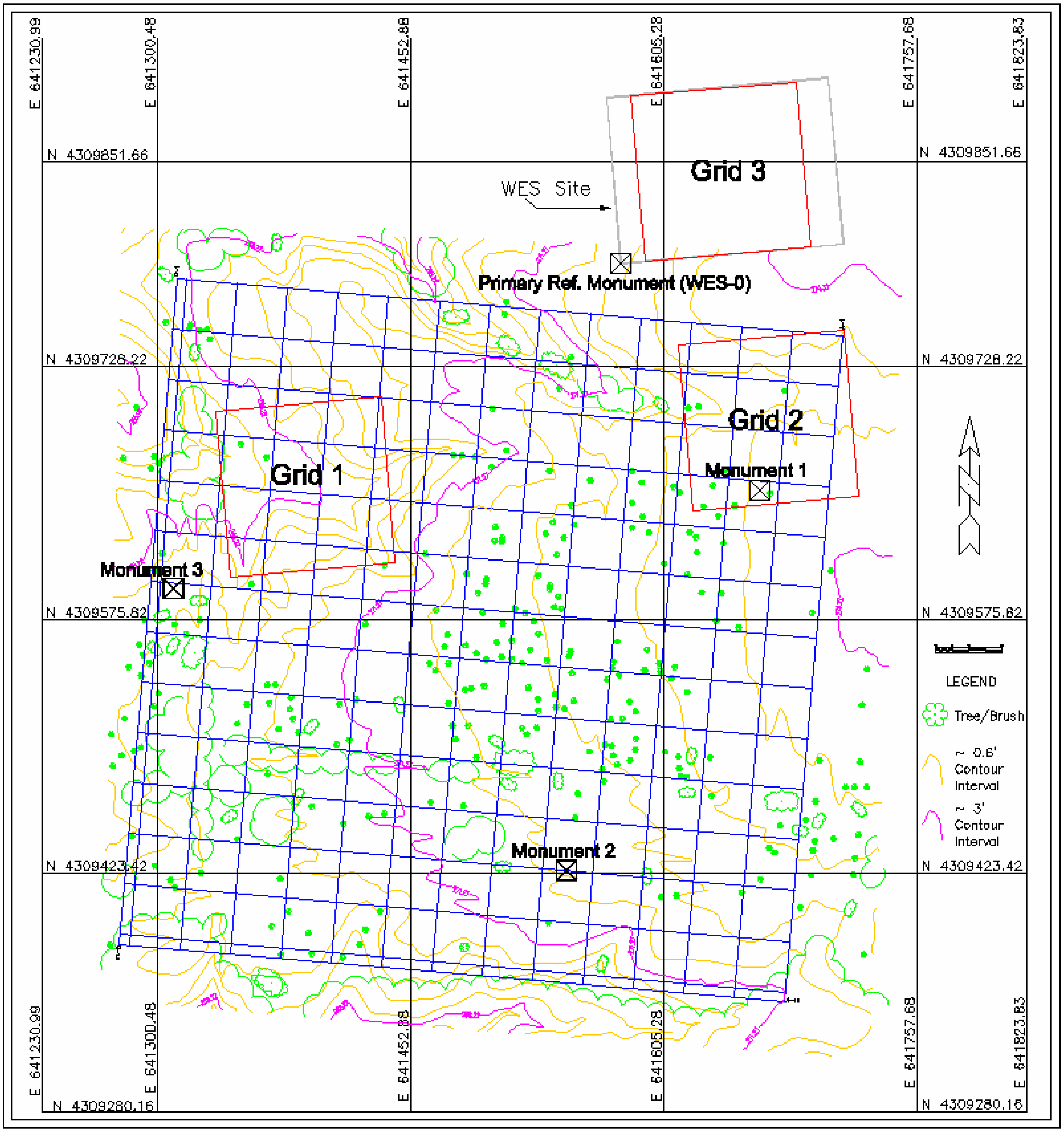


Figure 1: Site Map of JPG 2000 Grids

Plastic flags were placed around the perimeters of the three test grids (oriented to magnetic north), and survey control points were available on or beside all three grids. Twelve inert, cleaned, and degaussed ordnance types, ranging in size from 20mm to 155mm, were emplaced on the three test grids, together with representative non-ordnance (clutter) items and basaltic samples.

A site manager was provided to coordinate and supervise activities and access, record daily observations, monitor safety procedures, and control demonstration operations. A trailer (with telephone and electrical power), mobile radios, equipment storage facilities, portable toilet, samples of emplaced ordnance items, and a trench 2 meters long and 0.75 meters deep for calibration and self-testing were also made available on site.

4 Demonstration Approach

4.1 Discussion of JPG Work Plan

NAEVA (with GPA) was scheduled to demonstrate at JPG during the eight-day period September 11 through 18, 2000. The set-up for the exercise is described in ESTCP's work-plan by E. Cespedes (WES) and NAVEODTD. Multiple samples of twelve inert ordnance types and a variety of non-ordnance and clutter items were emplaced on each of three one-hectare test grids. The schedule and budget allowed approximately two days on each grid, two days for additional decay curve measurements (on new ordnance samples), high frequency – medium frequency tests, and survey measurements on a small self-evaluation test grid (Grid 4-1) over objects emplaced on the surface and in a small trench.

4.2 Data Acquisition

EM-63 data was acquired on the three one-hectare test grids, starting with Grid 3, which was conveniently located (near the trailer and a GPS reference monument) and posed the least topographic problems (relatively smooth, dry, and level, with few trees and other obstructions). Data was measured in narrow blocks or lanes ten meters wide, over the full one hundred meter north-south extent of each grid. This was done due to memory limitations in the EM-63, and to avoid longer-term zero calibration drift (approximately 40 to 60 minutes per 10m lane). Figure 2 illustrates surveying with the EM-63 on Grid 3. North-south ropes were spaced two meters apart to ensure straight survey lines with a 0.5m line spacing. Each lane was numbered in order from west to east (3-1, 3-2, … 3-10, for example). Each raw (binary) lane file contains approximately 2 Mb of data. When necessitated by GPS or other data problems, repeat lane files were measured, and named 3-2b, 3-2c, etc. GPS positions were acquired at a rate of one per second, and EM-63 readings were collected at a rate of 5 per second yielding a data density of one reading approximately every 20 cm.

Figure 2: Traversing Grid 3 with the EM-63
(Ropes at 2m intervals)

The EM-63 was operated on a non-metallic test table in static mode for 100 seconds at the beginning and end of each lane file, in order to zero the instrument (away from possible background response) and check for calibration drift after each survey period. Figure 3 illustrates EM-63 zeroing in air before grid lane surveying (and also the GPS base station set up). A standard 3.5” iron calibration sphere was placed at zero depth approximately five meters north of the north end of the first survey line in each lane, in order to verify stable amplitude response. This initial line was surveyed in north and south directions, in order to verify data repeatability and satisfactory positional latency (lag) corrections.

Zeroing of the EM-63 before surveying

GPS Base Station set-up

Figure 3: Set-up of Equipment

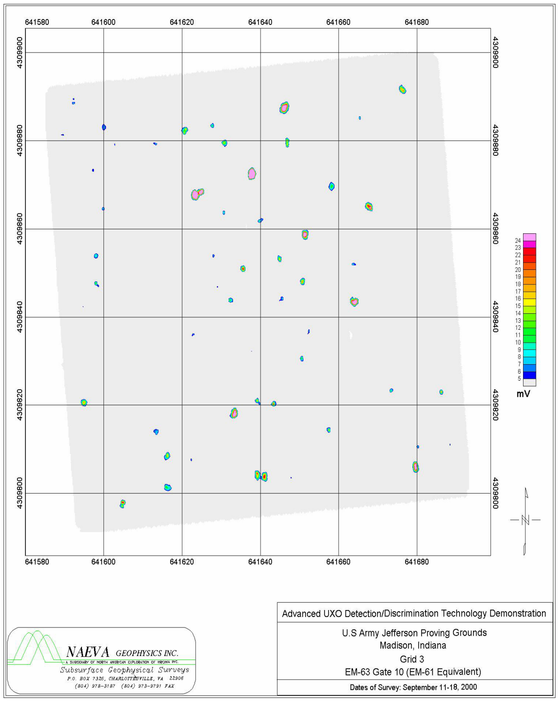


Figure 4: Contour Map From Grid 3

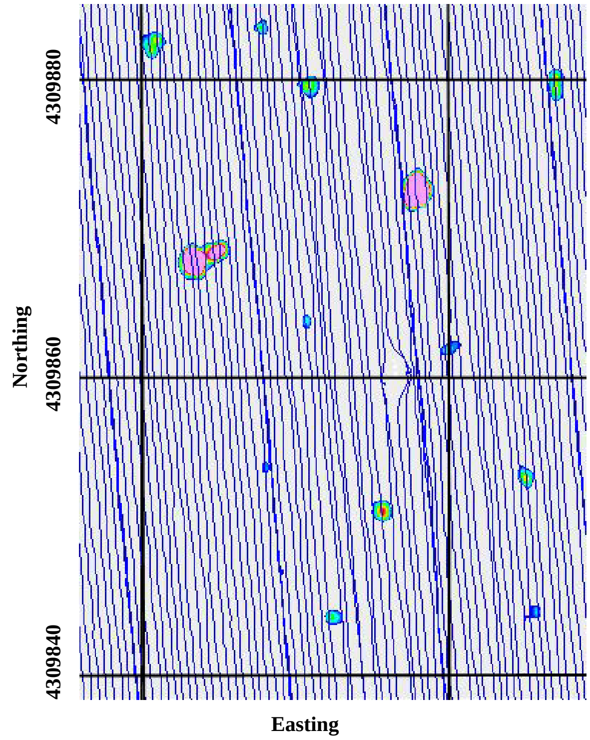


Figure 5: GPS Path For Grid 3

Figures 4 and 5 show contoured data from Grid 3 (Figure 5 is a close-up, showing recovered instrument path and anomaly details).

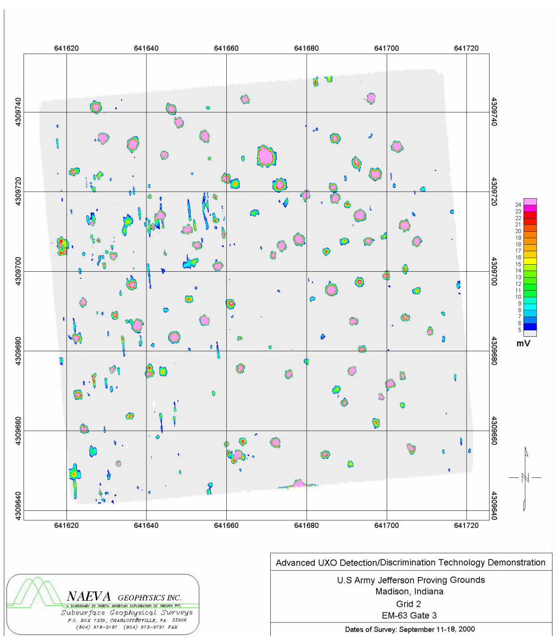


Figure 6: Contour Map From Grid 2

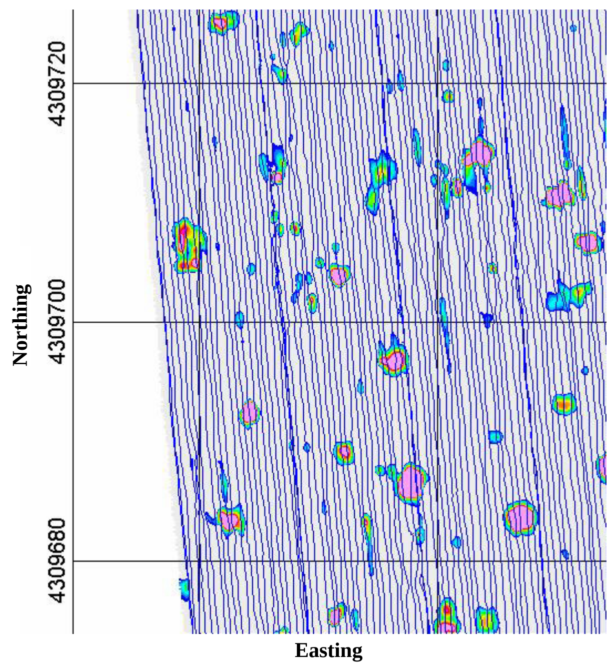


Figure 7: GPS Path For Grid 2

Figures 6 and 7 show similar results for Grid 2, which had more topographic irregularity and a greater target density.

4.3 Data Quality Control

As mentioned, the EM-63 was static tested for zero calibration and instrument (plus ambient) noise at the beginning of each survey lane file. The first line was repeated (bi-directional) to verify amplitude and location repeatability. As soon as the file was complete, it was checked for data gaps and/or poor GPS position recovery, and portions were repeated if necessary (generally, due to poor satellite availability).

Figure 8 shows GPS position checks for file 3-8b; black denotes GPS first quality "fix", while red denotes GPS second quality "float". "Float" was sometimes, but not always, usable. Figure 9 shows a similar plot for grid lane 1-1, where there were persistent satellite availability problems near trees on the west side of the grid.

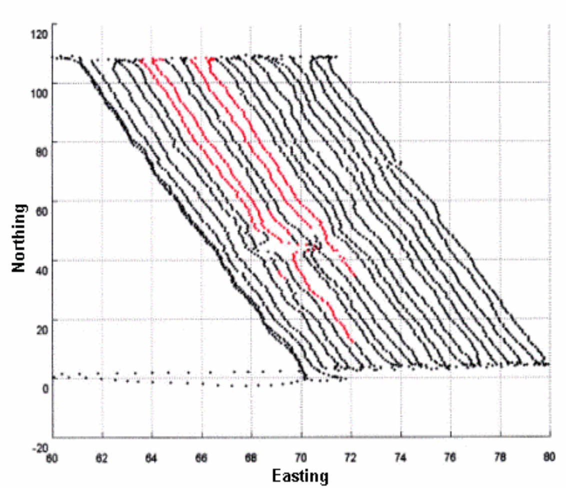


Figure 8: Check Ashtech GPS Positions

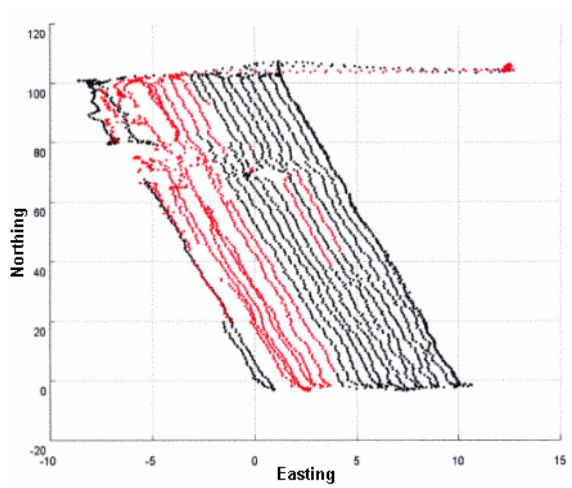


Figure 9: Check Ashtech GPS Positions

The repeatability of the first line in each grid lane file (and the amplitude response of the calibration sphere) was also verified, and terrain noise was inspected. Examples of data repeatability were given in the Blossom Point report. It soon became clear that spatially variable background response was present in the early time gates at the JPG grids, and would have to be removed from the field data before target decay curves could be compared. Figure 10 and 11 illustrates variable background response (and perhaps some calibration drift) from Grid 3 data collected in both high frequency (20 gates) and medium frequency (26 gates) modes. It is apparent that the medium frequency data has much worse noise (evidently due to changes made by Geonics since our Blossom Point field tests). For this reason, it was decided to survey the three grids with high frequency, and sacrifice the six late gates in order to improve signal to noise ratio.

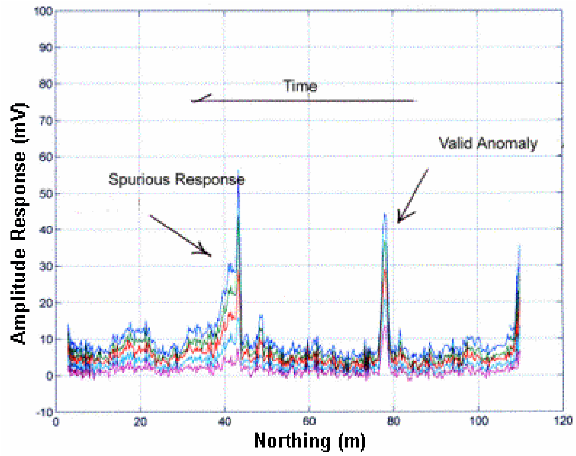


Figure 10: High Frequency

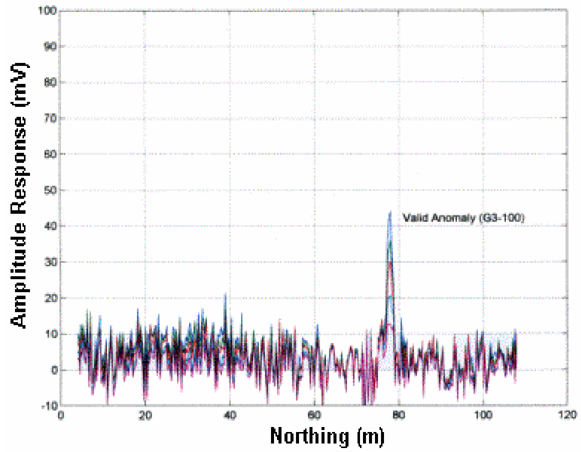


Figure 11: Medium Frequency

Inspection of data profiles revealed unusual early gate anomalies that were very abrupt on the initial side, and then decayed in the direction of instrument motion. These were not repeatable, and are evidently an artifact of mechanical shock. Figure 10 shows one of these "spurious" anomalies, and a valid anomaly for comparison. Note that the spurious anomaly was not present in the medium frequency data set. These spurious features were auto-picked by the software and were identified as targets on the preliminary target lists, but were deleted manually from our final target lists.

4.4 Additional Decay Curve Calibration Measurements

Additional (different) inert ordnance samples were made available at the JPG demonstration. Bench test decay curve measurements were made on these additional items during the period September 17 and 18, in order to check variability. These samples were spun through all inclinations (starting at horizontal (n), and rotating through nose-down, horizontal (s), nose-up, and back to horizontal (n). Figure 12 illustrates these ordnance bench tests in progress.

Figure 12: Bench Test on Ordnance Samples

Figure 13 shows a bench test data file (25h23a3b) in two ways. First, the sequential readings as the test sphere and each ordnance item is spun at 25cm depth (note, this data is unleveled, so the zero drift may be seen). Second, the decay curves (across the 20 high frequency time gates) are shown; with each item a different color. Note that the sphere (blue), 57mm (black), and 7" 60mm (red) exhibit very similar decay curve shapes, whereas the 9" 60mm is distinct.

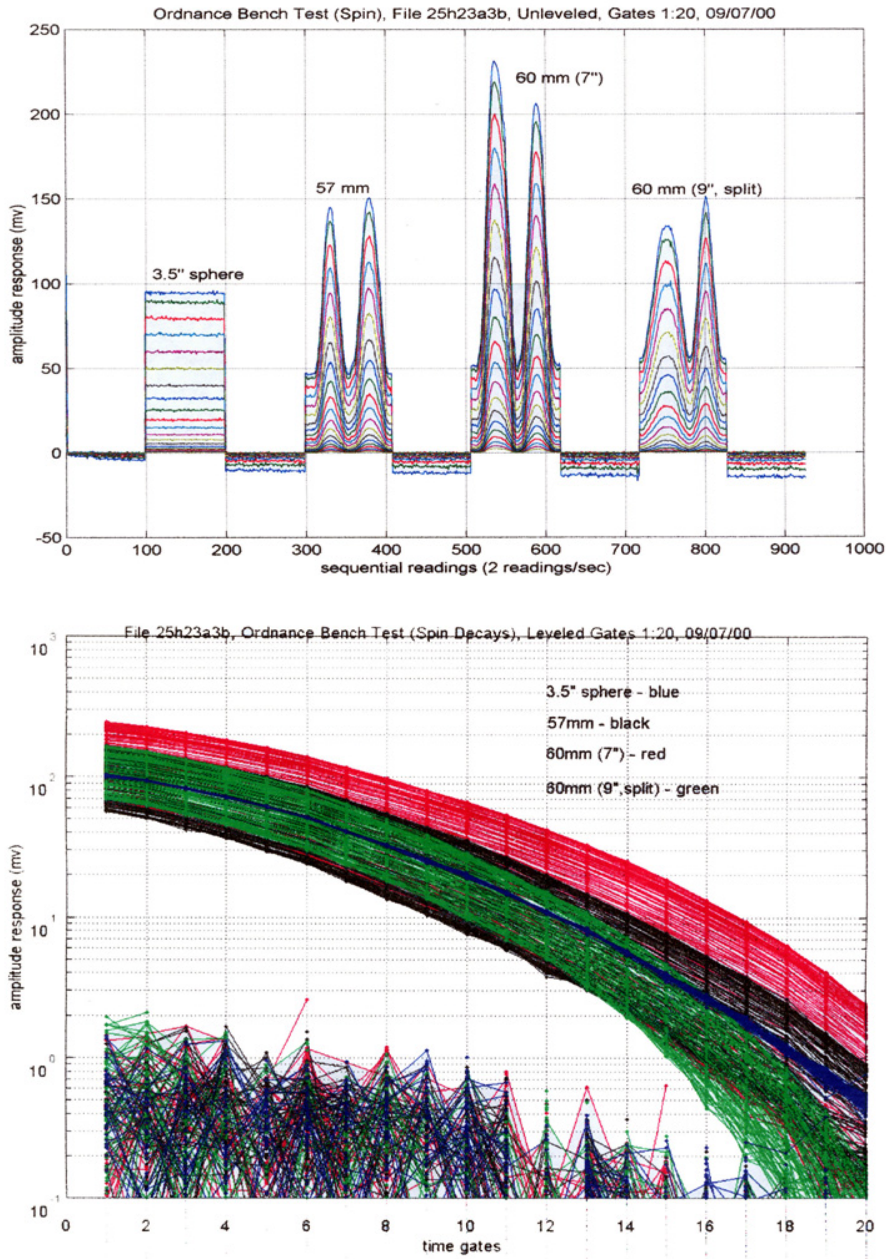


Figure 13: Bench Test Data files

4.5 Data Processing

The basic EM-63 data processing and analysis steps are as follows:

1) **GPS checks:** GPS position integration (interpolation, latency corrections).

2) **Auto-Leveling** (all gates): to remove decaying background response and calibration drift across all time gates.

3) **Visual Inspection** (profiles and plan contour maps) and **Editing:** to remove bad data points, recognize data gaps, cut outside the grid, and split lines for GEOSOFT. Repeat data acquisition (DAQ) if necessary.

4) **Target Picking:** selection of all targets over an appropriate amplitude response threshold established by yield curve or data frequency distribution analysis. Harvest selected decay curves.

5) **Comparison of Decay Curves:** from targets and bench calibration tests for expected ordnance items, computation of Chi-Squared measure of misfit.

6) **Prioritization of target list:** in order of increasing chi-squared misfit.

Auto leveling and target picking are probably the most important and difficult data processing steps.

Details of the EM-63 data processing and analysis steps are as follows:

a) **GPS Integration**: The first step in the data processing was the assignment of a position to each EM-63 measurement, by interpolating between the GPS readings, which most closely preceded and followed the measurement, according to the data acquisition clock after it had been corrected for latency.
b) **Cropping**: All points that were not within 0.5 m of the grid were discarded, because turning the instrument caused the instrument to pitch, which led to artifacts in the data.

c) **Background Subtraction**: Next, the background level in each gate was established by estimating the mean of all points within a fixed distance and within a set time of the reading. In order to minimize the effects of outlying readings, a non-parametric estimate was used. The sizes of the spatial and temporal windows were chosen to be larger than the size of a target anomaly, so that the targets did not raise the local background, but small enough that the instrumental drifts and terrain noise would still be subtracted. The spatial window had a half width of 8 m, and the temporal window had a half width of 20 s. The measured background was not very sensitive to these values, however, as long as the windows were of reasonable size.

d) **Visual Inspection and Editing**: Before targets were picked, profiles and contour maps were inspected in order to remove bad data points, recognize data gaps, cut outside the grid, and split lines for GEOSOFT. In grids where the DAQ was repeated, the data were merged to form one data set.

e) **Target Picking**: Based on an inspection of the data frequency distribution, a threshold of 3 mV was selected for a synthesized EM-61 equivalent gate, and a threshold of 5 mV was selected for gate 3. The number of low-amplitude clutter items picked is very sensitive to these threshold values; the values were chosen to eliminate as many clutter items as possible while still permitting detection of targets at those depths which they are expected to be found. Most targets were found both in gate 3 and the EM-61 equivalent gate, but it was expected that smaller objects would be found preferentially in the earlier gate, and the EM-61 equivalent gate would find large, deep objects. The 5 mV threshold in gate 3 yielded on-site target picks of 144 in Grid 1, 206 in Grid 2, and 105 in Grid 3. Target yields increase more or less exponentially as the threshold is lowered. Figure 14 shows approximate yield curves for the three one-hectare demonstration grids (adjusted for the ‘bogus’ noise spikes which were removed from the off-site target lists).

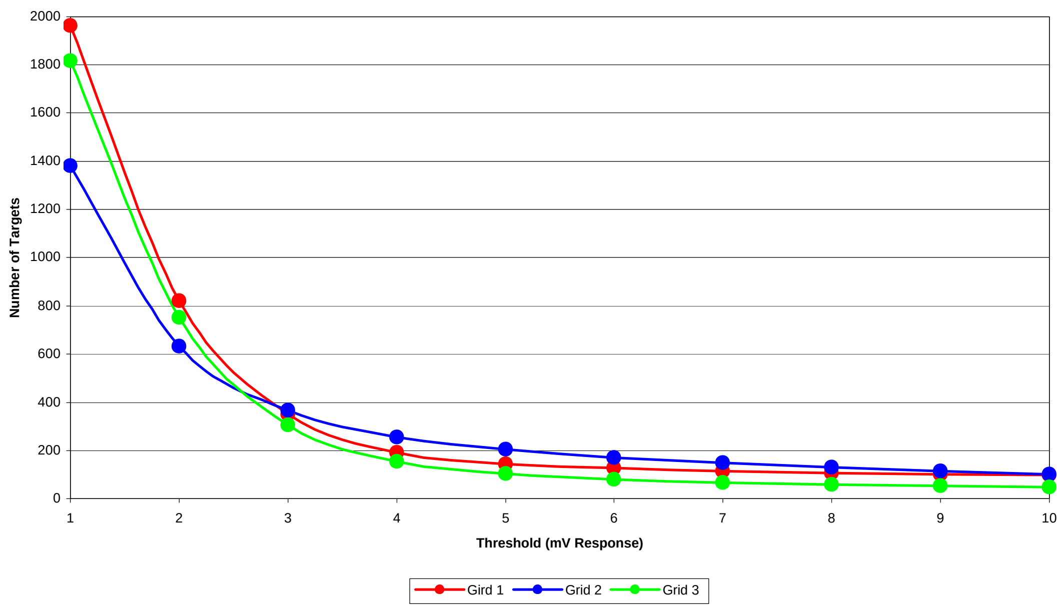


Figure 14: EM-63 Gate 3 Yield Curves
'Adjusted' Number of Targets (on-site)

f) **Harvesting Decay curves**: All data points within 0.2 m of the target position (calculated from gridded data) were averaged to find a decay curve for that target. In the event that there was only one data point within 0.2 m, the allowable distance was increased to 0.25 m. Some targets did not have any measurements within 0.25m; for them, the allowable radius was increased in small steps until a data point was found within the radius. One marginal target did not have any data points within 0.6 m, and was discarded from the analysis. Most likely, this target was the result of extrapolation by the gridding software, as most targets have a half width of approximately 0.5 m. As shown in Figure 15, this harvesting process yielded between one and five decay curves for averaging and analysis, depending upon target location with respect to nearby survey lines.

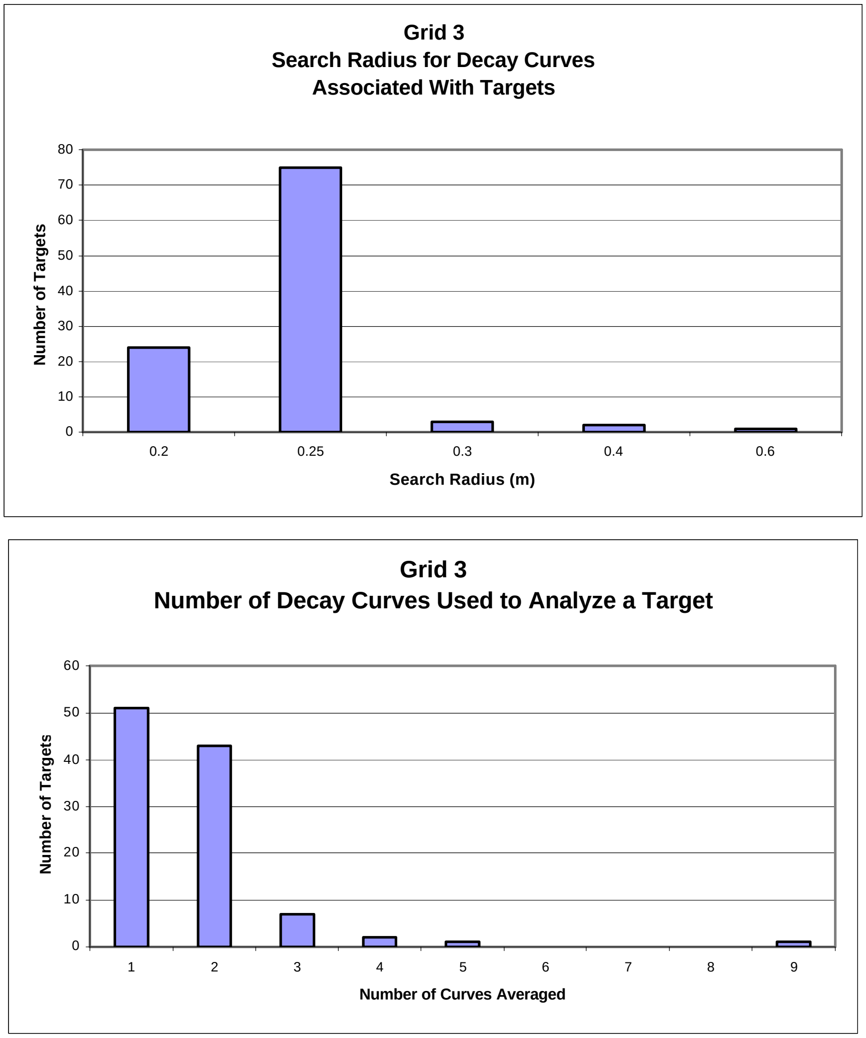


Figure 15: Histograms for Target Selections of Grid 3

Because the decay curve shape changes as the instrument moves over a target, one might be concerned that the averaging of target decay curves would produce an average curve which does not match the item's decay curves in the database. However, all decay curves (to first order, at least) are a linear combination of the principal decay curves on the principal axes (transverse and axial) of the object. When several of these target curves are averaged, the result is still a linear combination of the two principal curves. The averaged decay curve is therefore still representative of the object. See section 4.6 for a more detailed discussion of chi-squared (χ^2) target decay curve matching.

g) Comparison of Decay curves: The comparison of the harvested curves to the calibration curves is described in the section below, and yielded a chi-squared (χ^2) value corresponding to the best fit to any ordnance item.

h) Prioritization of target list: The picked targets were prioritized in order of increasing χ^2 value.

Auto leveling and target picking are probably the most important and difficult data processing steps. Auto leveling is still not commercially available for the two data channels (top and bottom coils) of the EM-61, and is clearly necessary for the 20 – 26 channels of the EM-63 (far too much data to level manually). The threshold decision is critical, because it determines the number of terrain response ‘false positives’ (clutter) selected for analysis. Lowering the threshold will increase true positives (detection), but also increase false positives. While the analysis of the final decay curves described in the next section is novel, it is a step which does not require as much interpretation and judgment on the part of the analyst, and is thus more straightforward to apply.

4.6 The c^2 Test

In the limit that the target object is small relative to the distance to the instrument, one can treat the object as a point object with a tensor response. The object then has 3 characteristic decay curves corresponding to the three principal axes (or two if it is rotationally symmetric), and the decay curve from any orientation of the object may be expressed as the sum of these characteristic decay curves.

4.6.1 Library Decay curves

The decay curves representative of each object were found by spinning the objects under the EM-63. For the smaller ordnance, it was found that the decay curves were, as expected, the sum of the horizontal and vertical decay curves. For the largest ordnance, however, 0 deg inclination and 180 deg inclination decay curves were often different, presumably because the ordnance (at a typical depth) is large enough that it cannot be treated as a point object. The decay curves measured between 0 deg and 90 deg, however, were generally fit well by a combination of those two curves. Likewise, the decay curves measured between 90 deg and 180 deg were fit well by a combination of those. In these cases, a separate entry was put in the library for each. The 5 in projectile and the 105 mm mortar were even more complex, and each was given three entries in the object table, to account for the complexity of the decay curve variation.

4.6.2 Matching

Each target decay curve was compared to each library object, using a χ^2 test. Writing the target decay curve as a vector with 26 components: **x**, and the library curves as vectors **y** and **z**, the linear combination of the library curves which best fits **x** is found by varying the coefficients (a and b) of both vectors in order to minimize χ^2:

$$\chi^2 = \sum_i \left(\frac{x_i - a\, y_i - b\, z_i}{\sigma_i} \right)^2 ,$$

where σ_i is the expected standard deviation of the measurement in gate i.

These errors were estimated by adding in quadrature the measured instrumental error in each gate with 0.5% of the signal in that gate. This latter term corresponds to the expected variance between ordnance of the same type, as determined from the previous tests at Blossom Point.

The χ^2 measured for each target (normalized by the modulus of error), was used to prioritize (and classify) each target as possibly ordnance like, or as non-ordnance like. Based on the tests at Blossom Point and a small sample collected over known ordnance at the Jefferson Proving Ground, it was not expected that there would be many (if any) ordnance items would have χ^2 values greater than 100, and thus this was used as the cutoff for high probability non-ordnance.

The χ^2 value is a measure of how unlikely it is that the target matches a library item. A target can have a low χ^2 either because it fits the curve corresponding to a known ordnance sample quite well, or because the signal to noise is poor. In the latter case, it is reasonable that the item be on the dig list, because if it is possible that the item is ordnance, the item should be investigated further.

4.7 Target Lists Provided to ESTCP

Three sets of prioritized target lists were provided to ESTCP as required. Each set consisted of six lists (two for each grid, with and without considering 20mm projectiles). The first (preliminary) lists were submitted on September 19, the day NAEVA-GPA left the JPG Demonstration. These automatically picked target lists included the "bogus" mechanical amplitude responses already mentioned. Revised target lists were submitted several weeks later, after the spurious (one line) responses had been identified and removed. This resulted in substantial reductions in the target lists, probably without any loss of true positives.

Target List	Revisions	Grid 1	Grid 2	Grid 3
Preliminary		144	206	105
	Deleted Targets	-21	-96	-33
Revised		123	110	72
	Restored Targets		+13	
	Basalt	+5	+7	+6
Final (with MTADS)		128	130	78

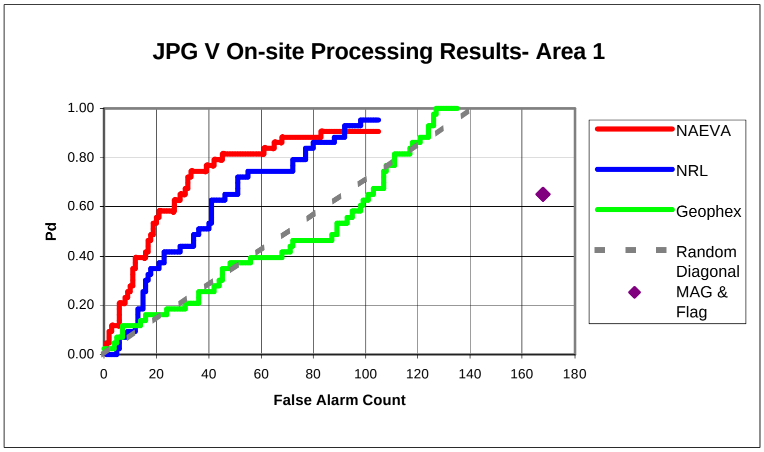
The selection of additional magnetic objects detected by MTADS (but not by EM) was somewhat subjective, but resulted in the addition of 5 targets for Grid 1, 20 targets for Grid 2 (13 preliminary targets with weak EM response restored, and 7 new non-EM targets), and 6 targets for Grid 3. The new targets were, of course, placed at the ends of the prioritized target lists, because they are judged to be magnetic (detected by MTADS) but not metallic (not detected by EM-63). That is, they are probably basalt samples.

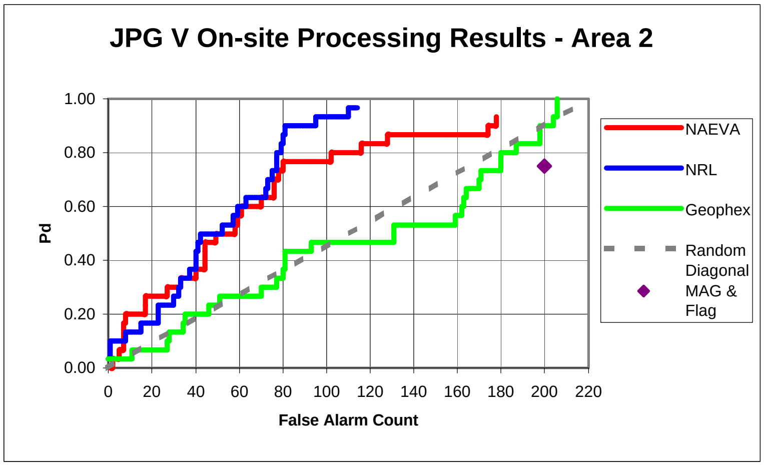
5 Performance Assessment

5.1 JPG Demonstration Performance

NAEVA's performance results for Grids 1, 2, and 3 are best summarized by Receiver Operator Characteristics (ROC) curves generated from the initial (on-site) and subsequent (off-site) prioritized target lists (with and without 20mm). Figure 16 displays the on-site (with 20mm) ROC curves, and also the Percent Detected vs. False Alarm Count (Pd/FAC) points for baseline 'mag-and-flag'. The high initial slope of the NAEVA ROC curve indicates good detection and discrimination (comparable to Naval Research Lab (NRL), better than Geophex, and

considerably better than 'mag-and-flag' across all three grids). The NAEVA EM-63 results failed to reach 100% detection at any of the three grids. This is because the gate 3 threshold was set conservatively at 5 mV. The detection would probably have reached 100% at a 4 mV threshold (as shown for Grid 3 in the following self-assessment discussion), but at a cost of additional 'false positives'. Of course, there is nothing 'false' about false positives; they are the repeatable responses of other actual objects in the ground. The NAEVA single point Pd/FAC performance meets Kaho'olawe requirements.





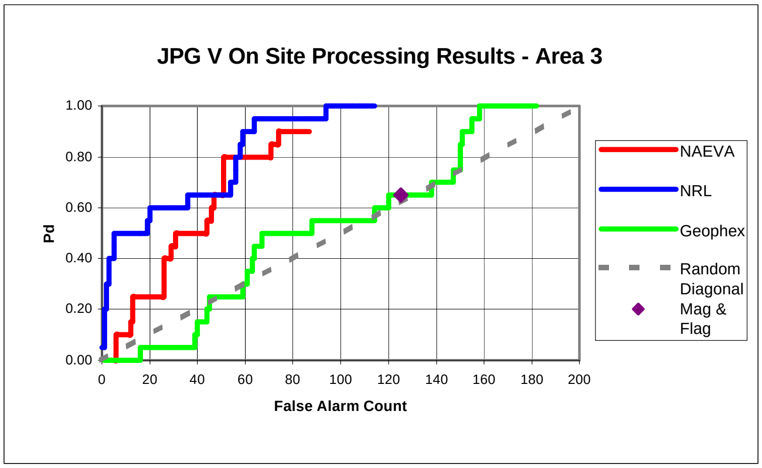


Figure 16: Composite ROC Curves

NAEVA's use of the MTADS ground magnetometer data was limited and simple. The MTADS data was used to revise a few decisions regarding removal of 'bogus' anomalies (probably due to mechanical shock), and to identify a few magnetic anomalies with no EM response (probably emplaced basalt boulders) and <u>add</u> them to the bottom of the target lists for each grid. The overall effect of this was to increase the 'false positive' counts. There was no attempt at 'fusion' of magnetic and EM advanced data analysis algorithms. This would certainly improve UXO discrimination, but it is a much more difficult development effort, beyond the scope of our present project.

5.2 Self-Evaluation Grid 4-1

In order to self-evaluate the EM-63 decay curve discrimination algorithms under field conditions, NAEVA-GPA conducted a small survey over six selected sample ordnance items and a 3.5" test sphere. The two larger items (4.2" mortar and 152mm projectile) were placed in the shallow trench provided, and the other five metallic items were placed on the surface (horizontal, zero depth). A sample boulder of Kaho'olawe basalt was also placed on the ground surface at the north end of the "grid". This small test grid was called 4-1. The survey results (for gate 10) are shown in Figure 17. Note that there is no response (above the 5 mV threshold) over the basalt sample. The EMFIT decay curve-matching algorithm correctly identified all of these 4-1 sample ordnance items, with a chi-squared "misfit" of 55 or less. The chi-squared fit data from this test grid are presented in Table 1.

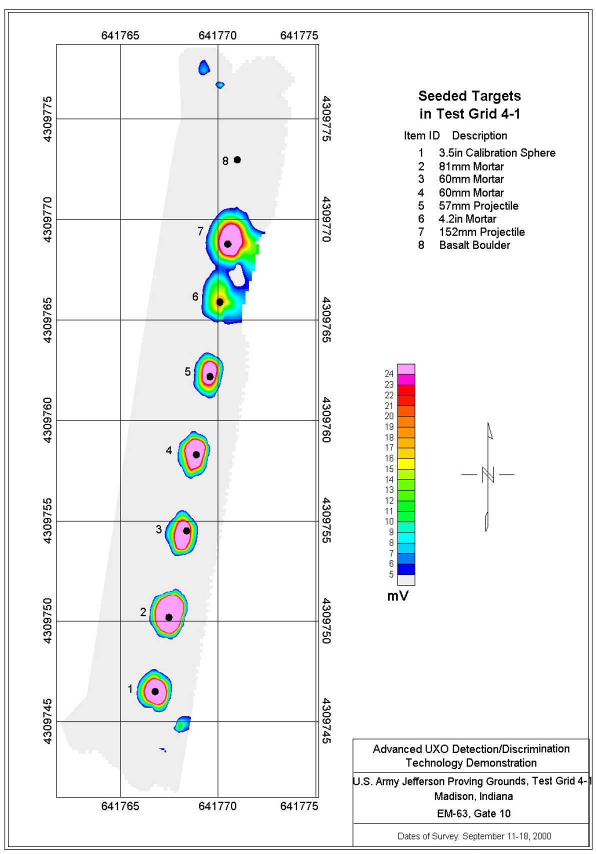


Figure 17: Contour Map of Test Grid 4-1

5.3 JPG5 Relevance to Kaho'olawe

Several boulders of magnetically susceptible Hawaiian basalt (10 – 15 cm in diameter) were emplaced in Grids 1, 2, and 3, to test discrimination of basalt EM amplitude response, a problem at Kaho'olawe. As mentioned, the EM-63 did not detect the sample basalt boulder in bench tests or on self-test Grid 4-1. Basalt is non-conductive, and has a magnetic susceptibility some thousand times less than that of iron. Therefore, a basalt body must be at least ten times greater in diameter (a thousand times bigger in volume) in order to exhibit significant EM-61 or EM-63 response. A cubic meter or more of basalt, under the EM-61/63 footprint, should cause a problematic background response, especially in early time. (Smaller volumes of basalt might affect smaller EM coil configurations.) Spatial variations in background response at Kaho'olawe due to larger volumes of variably weathered basalt and basaltic soils pose a difficult problem, which auto-leveling, for variable background response, is intended to address.

5.4 Analysis of Grid 3 Results (Truth Table)

The JPG Grid 3 truth table has recently been released, making it possible to evaluate decay curve detection and discrimination as a function of target size, depth, and amplitude response. Results are summarized graphically in Figure 18. All Grid 3 ordnance (red, blue, and yellow triangles) and non-ordnance (small uncolored squares) are plotted against mass (x-axis) and depth (y-axis). Two presumed basalt samples (green squares) are also shown. Four EM-63 gate 3 amplitude contours (threshold 5, 10, 15, and 25 mV) are also shown. These contours were determined by gridding and contouring the gate 3 amplitude response of all detected items which were emplaced. Ordnance that were not detected (outside the 5 mV threshold) are highlighted in blue. Ordnance which were correctly identified are highlighted in yellow. Ordnance which were misidentified by decay curve analysis are highlighted in red. It is interesting that both 57mm projectiles and almost all of the 60mm projectiles were misidentified. Most of the 60mm were misidentified as 81mm or 152mm. Parametric plots of decay curve shape were constructed in order to see why these were difficult to identify.

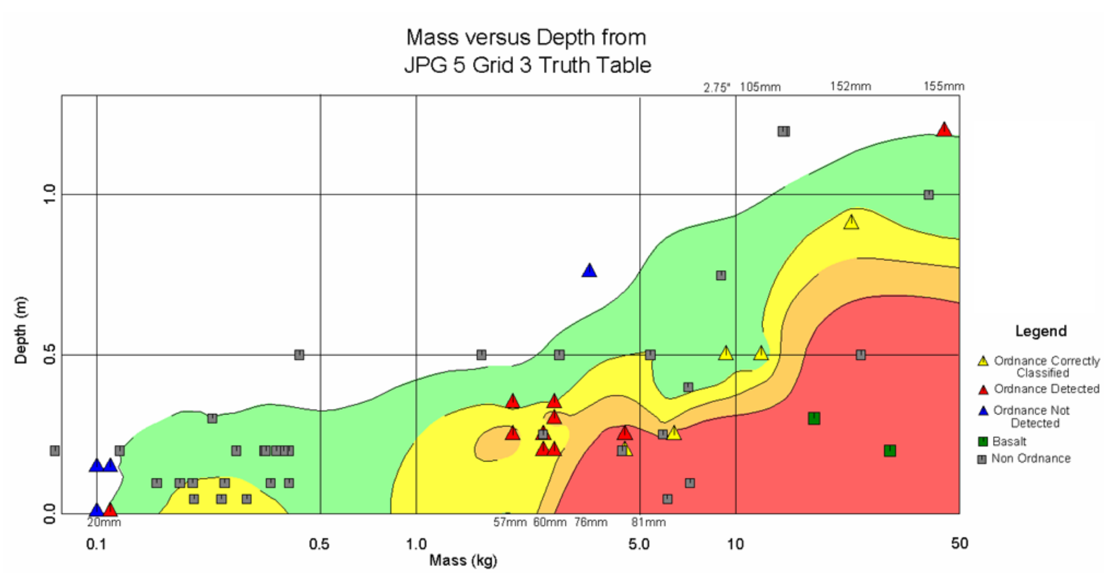


Figure 18: Contours of Gate 3 Amplitude (mV)

Parametric plots or decay curve shape for several of the ordnance samples, shown in Figure 19, reveal that the decay curve shapes for certain sample ordnance types overlap closely. On the other hand, the 9” long 60mm projectiles have very distinct decay curves. It is therefore easy to confuse 57mm and 7” 60mm with each other, and also with the 81mm mortar, 152mm projectile, and the 3.5” calibration sphere, especially if the response is noisy (object relatively deep for its size).

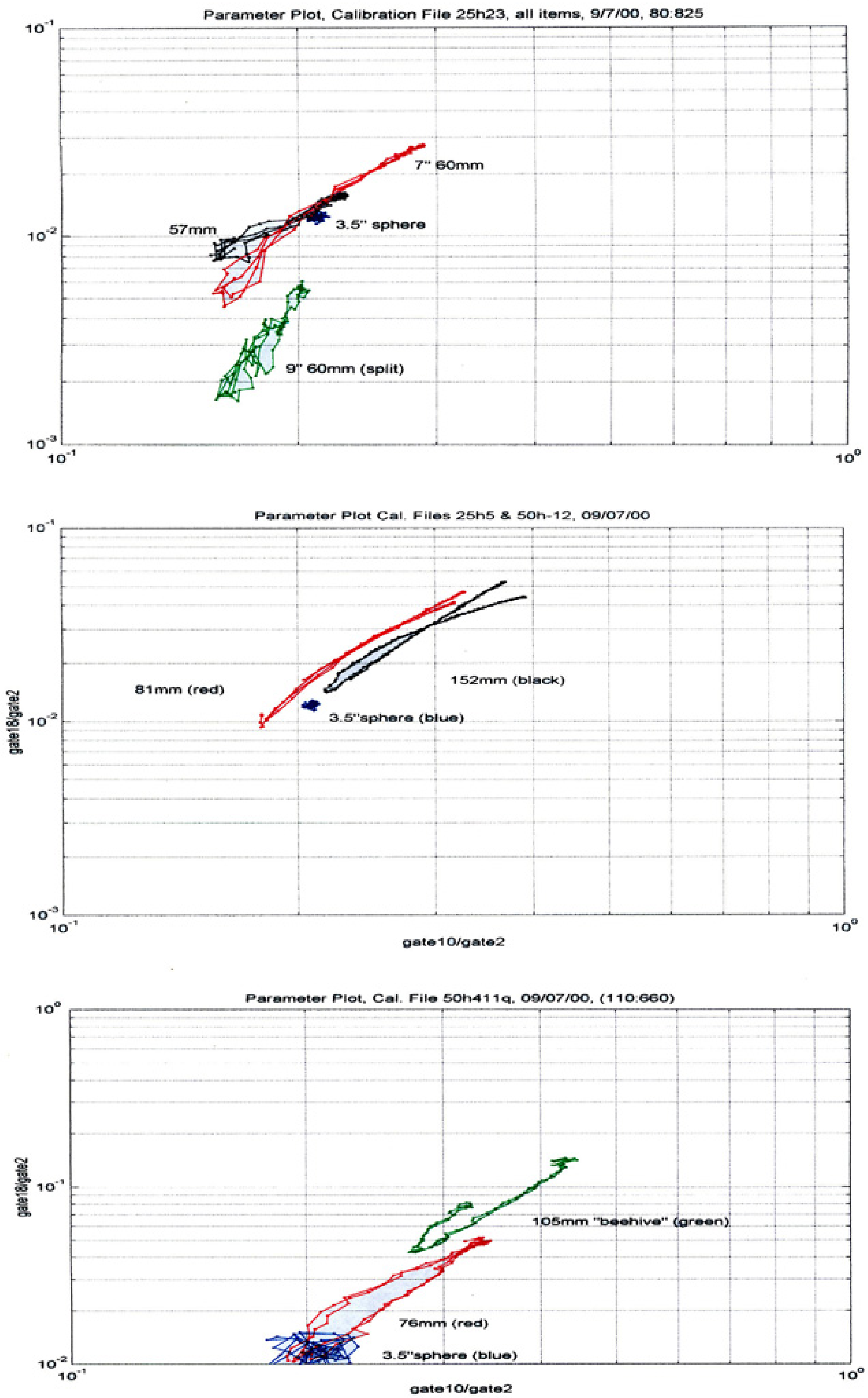


Figure 19: Decay Curve Shapes vs. Ordnance Types

Fortunately, this similarity of decay curves for different ordnance does not affect the prioritization of the target list, because targets are prioritized if they fit any expected ordnance type (in the chi-squared sense).

Regarding Grid 3 MTADS magnetic anomalies, of the six MTADS targets (with no EM response) selected, only one corresponds to a Grid-3 truth table target (3-110), which is evidently a basalt boulder. The other five correspond to no G-3 truth table target, the causes of these anomalies are unknown (but almost certainly real objects). The other G-3 truth table target that is evidently basalt (3-108) correlates with no MTADS or EM response. However, there is an MTADS and a weak EM anomaly approximately 2.5 meters to the east that is unexplained. Perhaps, item 3-108 is mislocated in the Grid 3 truth table?

6 Cost Assessment

6.1 Cost Performance

The following table presents estimated expected operational costs for the demonstrated technology when implemented, not including mobilization/demobilization costs. Costs are calculated based on an average daily rate and would increase or decrease based on the duration of any specific project.

Data Acquisition	
Labor	$ 1350/ day
EM-63 equipment	$ 350/day
GPS	$ 250/day
Materials	$ 100/day
Perdiem	$ 240/day
Data Processing	
Labor	$ 520/day
Software	$ 100/day
Materials	$ 40/day
Data Presentation	
Labor	$ 130/day
Materials	$ 10/day
TOTAL	$ 3090/day

6.2 Cost Comparison to Conventional Technologies

The following table presents a daily cost comparison of the demonstrated EM-63 technology to conventional EM-61 DGM technology.

Item	**EM-63**	**EM-61**	**Difference**
Data Acquisition			
Labor	$ 1350	$ 1350	$ 0
EM-61/EM31	$ 350	$ 250	$ 100
GPS	$ 250	$ 250	$ 0

Perdiem	$ 240	$ 240	$ 0
Materials	$ 100	$ 100	$ 0
Data Processing			
Labor	$ 520	$ 260	$ 260
Software	$ 100	$ 0	$ 100
Materials	$ 40	$ 40	$ 0
Data Presentation			
Labor	$ 130	$ 130	$ 0
Materials	$ 10	$ 10	$ 0
Total	$ 3090	$ 2630	$ 560

The cost matrix above indicates an estimated increase in daily operating costs of $560/day for the demonstrated EM-63 technology over EM-61 technology. This increase would be more than offset, however, if the EM-63 was even partially successful at discriminating true UXO targets from clutter, thus reducing the number of UXO excavations. NAEVA has limited exposure to costs for UXO excavations, but a figure published by the Army Corps of Engineers for the Ft. Ritchie, Maryland ECCA project was $670 per dig. Thus, eliminating just two digs per day would offset the additional costs of the demonstrated EM-63 technology. In practice, if an "average" daily EM-63 survey produced an average of 100 targets, and the demonstrated technology was able to eliminate **only 10%** of those targets from excavation, the cost savings would be over twice the entire cost of conducting the digital geophysical mapping and discrimination. Higher levels of successful discrimination would yield potential huge cost savings.

Specific to Kaho'olawe, the government reports, "As of 1 March 2000, contractors at Kaho'olawe had detected 12,121 subsurface anomalies and after digging they found that only 4 percent are UXO, 32 percent are false positives due to geologic variations and 64 percent are due to buried metal from both UXO and non-UXO-related materials." Using these figures, even if the demonstrated technology was only able to discriminate metal objects (both UXO and non-UXO) from magnetic rocks/soil, 32% of target excavations, over 3,800 targets, would have been eliminated with a cost savings of over $2,500,000 at a minimum (using the $670 cost per dig figure from Ft. Ritchie, Maryland . . . presumably the cost per dig at Kaho'olawe would be much higher).

Comparisons should also be made to "mag and flag" detection technology for which NAEVA does not have cost figures. Recent results from ESTCP's JPG 2000 report indicate "mag and flag" detection percentages (Pd) of only 65 to 70 percent, and a very high false alarm count (FAC). Thus, the demonstrated EM-63 technology should have huge cost and performance advantages over "mag and flag" technology.

7 Regulatory Issues

There were no regulatory issues in connection with NAEVA's ESTCP demonstration performance at JPG. The primary regulatory issue, which will affect the adoption of discrimination technology such as EM-63, will be gaining the confidence and approval of Federal, State, and local regulators, stakeholders, and users. Acceptance by organizations such as the Army Corps of Engineers and Naval Facilities and Engineering Command will be needed in order that future RFP's will include such innovative technology. This controlled site ESTCP demonstration (JPG-2000) is the first to employ realistic conditions, which will allow side-by-side comparisons of discrimination performance, production rates, and costs. Acceptance of

discrimination technology (that is, not digging some of a prioritized geophysical target list) ultimately requires a cost/risk evaluation by the regulatory agencies.

8 Technology Implementation

The next step for EM-63 discrimination technology will be to develop adaptations (revised field procedures and new data analysis algorithms), which will work at Kaho'olawe. As we understand it, there are several serious problems with the application of EM metal detection at Kaho'olawe:

a) Very noisy data, probably due to mechanical vibration as the instrument transits over bare, rocky ground. This may have been improved by recent development of a ''compensator coil'' and may also be helped by slower survey speeds.

b) Highly variable background response (10's or 100's of mV) due to the high magnetic susceptibility of the half-space of basaltic material beneath the instrument. Auto leveling of this variable background will be much more difficult than it was at JPG.

c) Local, discrete anomalies (one – two meters wavelength) due to pockets of high susceptibility basalt or soil, which may be picked as targets and confused with metallic items.

Preliminary field-testing and experimentation with revised algorithms will be necessary in order to minimize noise, optimize auto-leveling, and then discriminate discrete basalt anomalies.

9 Lessons Learned

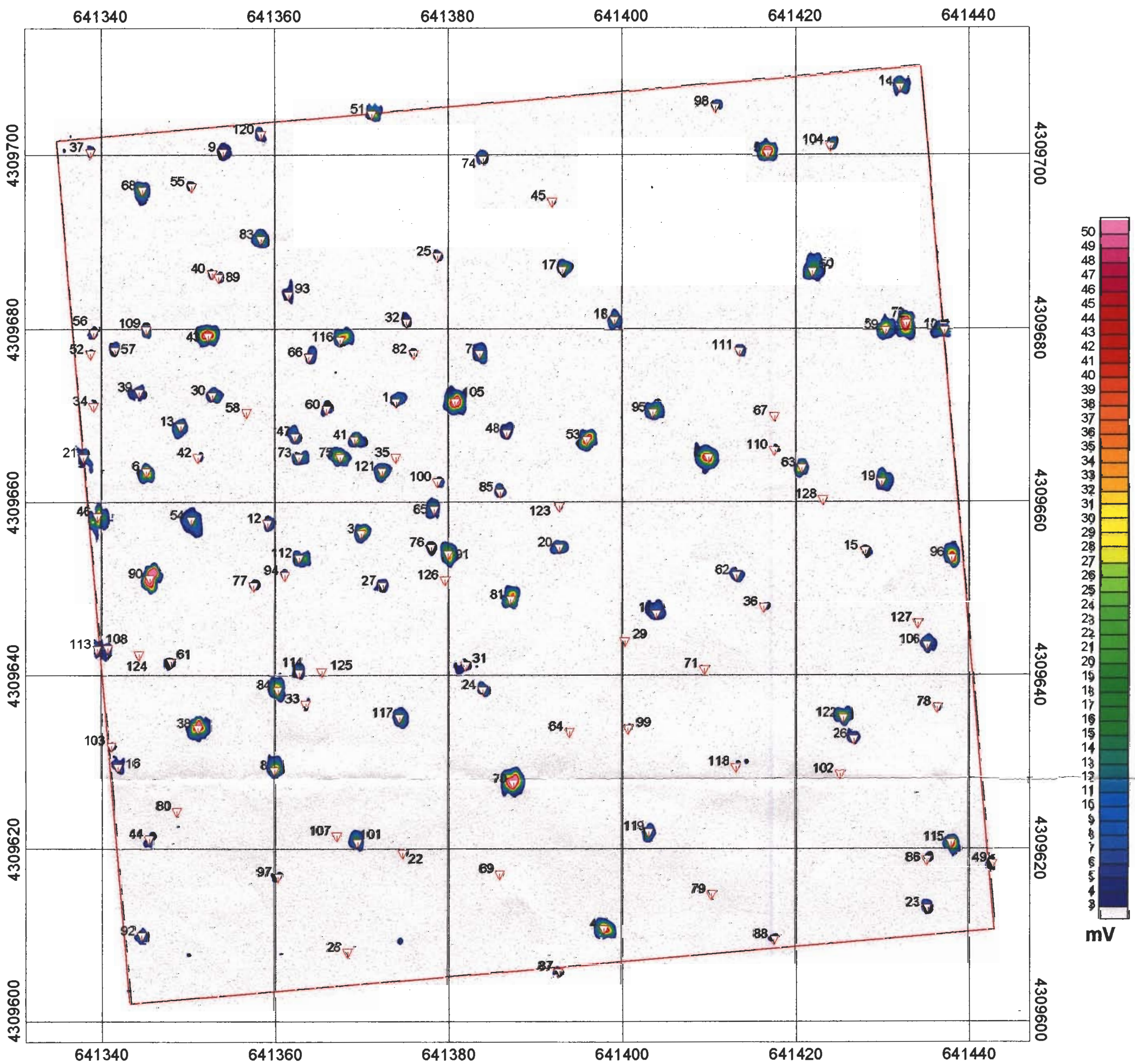
This report, and the prioritized target lists which were submitted, indicate the degree of discrimination that may be expected using EM-63 decay curve shape analysis alone. A greater degree of discrimination would be expected if the analysis included spatial anomaly shape analysis as well, because this would permit estimates of the target depth and intrinsic amplitude response tensor (related to size and shape). Integration of time decay (or frequency response) and spatial anomaly shape analysis is the most general approach to EM data analysis.

NAEVA – GPA did not arrive at JPG prepared to process on-site. This was because the software was still under development, and revised algorithms for auto-leveling of variable background response (encountered at JPG) were necessary. Our standard survey operating production plan, in general, would be to do preliminary QC processing on-site, and then utilize internat data transfer to enable remote advance data processing at a convenient workstation. This would be less expensive (no travel costs) and faster (better computer facilities). We regret that we were unable to process on site for purposes of time/productivity observation by the on-site manager at JPG, and would have done so if possible. NAEVA did deliver a prioritized target list before leaving JPG. Most of the actual advanced data processing (after leveling algorithm development) took place in the final 2-3 days. NAEVA – GPA will be prepared for on-site processing at the Kaho'olawe Controlled Site Demonstration, should that be a requirement of the work plan.

10 Conclusion

NAEVA and GPA appreciate the support of ESTCP for this very interesting project and JPG demonstration.

Appendix A: Grid 1 Target List and Contour Map



Scale 1:550

10 0 10

metre

Legend

Grid 1 Boundary

2 Selected Target
(See Prioritized Target List For Response and Location)

NAEVA GEOPHYSICS INC.
SUBSURFACE GEOPHYSICAL SURVEYS

Advanced UXO Detection/Discrimination Technology Demonstration

EM-63 Prioritized Targets
Grid 1 - Gate 10
U.S. Army Jefferson Proving Grounds
Madison, Indiana

Dates of Survey: September 11-18, 2000

DIG LIST: 1 Demonstrator: NAEVA Test Area: 1 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
1	4309671.6	641374	0.147	Ordnance	High	medium	-	0	Projectile	152mm
2	4309665.2	641410	0.444	Ordnance	High	large	-	0	Projectile	152mm
3	4309656.4	641370	0.215	Ordnance	High	medium	-	0	Mortar	60mm
4	4309610.8	641398	0.193	Ordnance	High	medium	-	0	Mortar	81mm
5	4309700.4	641416.8	0.331	Ordnance	High	large	-	0	Mortar	4.2in
6	4309663.6	641345.2	0.209	Ordnance	High	large	-	0	Mortar	81mm
7	4309677.2	641383.6	0.2	Ordnance	High	medium	-	0	Projectile	152mm
8	4309629.2	641360	0.246	Ordnance	High	large	-	0	Projectile	5in
9	4309700.4	641354	0.623	Ordnance	High	large	-	0	Mortar	81mm
10	4309680	641437.2	0.403	Ordnance	High	large	-	0	Projectile	155mm
11	4309647.2	641404	0.616	Ordnance	High	large	-	0	Rocket	2.75in
12	4309657.6	641359.2	0.0987	Ordnance	High	small	-	0	Mortar	60mm
13	4309668.8	641349.2	0.299	Ordnance	High	large	-	0	Mortar	81mm
14	4309708	641432	0.265	Ordnance	High	medium	-	0	Mortar	60mm
15	4309654.4	641428	0.38	Ordnance	High	medium	-	0	Mortar	4.2in
16	4309629.6	641342	0	Ordnance	High	small	-	0	Mortar	81mm
17	4309686.8	641393.2	0.372	Ordnance	High	large	-	0	Mortar	4.2in
18	4309681.2	641399.2	0.408	Ordnance	High	large	-	1.78	Projectile	105mm
19	4309662.4	641430	0.557	Ordnance	High	large	-	0	Projectile	152mm
20	4309654.8	641392.8	0.0944	Ordnance	High	medium	-	0	Projectile	57mm
21	4309665.2	641338	0.179	Ordnance	High	small	-	0	Mortar	60mm
22	4309619.6	641374.8	0.332	Ordnance	High	medium	-	0	Mortar	4.2in
23	4309613.2	641435.2	0.197	Ordnance	High	medium	-	0	Mortar	60mm
24	4309638.4	641384	0.169	Ordnance	High	medium	-	0	Rocket	2.75in
25	4309688.4	641378.8	0.304	Ordnance	High	medium	-	90	Mortar	4.2in
26	4309632.8	641426.8	0.601	Ordnance	High	large	-	0	Rocket	2.75in
27	4309650.4	641372.4	0.335	Ordnance	High	medium	-	0	Mortar	81mm
28	4309608.12	641368.49	1.82	Ordnance	High	large	-	90	Projectile	155mm
29	4309644	641400.4	0.784	Ordnance	High	large	-	0	Mortar	81mm
30	4309672.4	641352.8	0.0514	Ordnance	High	small	-	0	Mortar	81mm
31	4309641.2	641382	0.0737	Ordnance	High	small	-	0	Projectile	20mm
32	4309680.8	641375.2	0.237	Ordnance	High	medium	-	0	Mortar	81mm
33	4309636.8	641363.6	0.128	Ordnance	High	small	-	0	Projectile	57mm
34	4309671.2	641339.2	0.0799	Ordnance	High	small	-	0	Projectile	20mm
35	4309665.2	641374	0.232	Ordnance	High	medium	-	0	Projectile	155mm
36	4309648	641416.4	0	Ordnance	High	small	-	0	Projectile	20mm

DIG LIST: 1 Demonstrator: NAEVA Test Area: 1 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
37	4309700.4	641338.8	0.187	Ordnance	High	medium	-	0	Projectile	57mm
38	4309634	641351.2	0.469	Ordnance	High	large	-	0	Projectile	152mm
39	4309672.8	641344.4	0.305	Ordnance	High	medium	-	0	Projectile	20mm
40	4309686.4	641352.8	0.17	Ordnance	High	medium	-	15.6	Mortar	4.2in
41	4309667.2	641369.2	0.211	Ordnance	High	medium	-	0	Projectile	152mm
42	4309665.2	641351.2	0.298	Ordnance	High	medium	-	0	Projectile	20mm
43	4309679.2	641352.4	0.315	Ordnance	High	large	-	0	Mortar	4.2in
44	4309621.2	641345.6	0.21	Ordnance	High	small	-	0	Mortar	4.2in
45	4309694.8	641392	0	Ordnance	High	small	-	0	Projectile	20mm
46	4309658.4	641339.6	0.425	Ordnance	High	large	-	0	Projectile	152mm
47	4309667.6	641362.4	0	Ordnance	High	small	-	0	Projectile	20mm
48	4309668	641386.8	0.293	Ordnance	High	medium	-	0	Mortar	81mm
49	4309618.4	641442.8	0.227	Ordnance	High	medium	-	0	Mortar	60mm
50	4309686.8	641422	0.292	Ordnance	High	medium	-	0	Mortar	81mm
51	4309704.8	641371.2	0.635	Ordnance	High	large	-	0	Mortar	4.2in
52	4309677.2	641338.8	1.72	Ordnance	High	large	-	0	Mortar	60mm
53	4309667.2	641396	0.0895	Ordnance	High	medium	-	0	Projectile	57mm
54	4309658	641350.4	0.496	Ordnance	High	large	-	0	Rocket	2.75in
55	4309696.4	641350.4	0.0553	Ordnance	High	small	-	0	Projectile	20mm
56	4309679.6	641339.2	0.368	Ordnance	High	medium	-	0	Rocket	2.75in
57	4309677.6	641341.6	0.433	Ordnance	High	large	-	0	Rocket	2.75in
58	4309670.4	641356.8	0.788	Ordnance	High	large	-	90	Projectile	105mm
59	4309680	641430.4	0.255	Ordnance	High	medium	-	0	Mortar	60mm
60	4309670.8	641366	0.399	Ordnance	High	large	-	0.149	Projectile	105mm
61	4309641.6	641348	0.145	Ordnance	High	medium	-	0	Projectile	20mm
62	4309651.6	641413.2	0	Ordnance	High	small	-	0	Projectile	20mm
63	4309664	641420.8	0.0271	Ordnance	High	medium	-	0	Rocket	2.75in
64	4309633.6	641394	0	Ordnance	High	small	-	0	Projectile	20mm
65	4309659.2	641378.4	0.163	Ordnance	Low	medium	-	0	Mortar	60mm
66	4309676.8	641364	0	Ordnance	Low	small	-	0	Rocket	2.75in
67	4309670	641417.6	0	Ordnance	Low	small	-	0	Projectile	20mm
68	4309696	641344.8	0.359	Ordnance	Low	large	-	0	Projectile	76mm
69	4309617.2	641386	0.67	Ordnance	Low	medium	-	0	Projectile	105mm
70	4309627.6	641387.6	0.424	Ordnance	Low	large	-	0	Projectile	5in
71	4309640.8	641409.6	0.503	Ordnance	Low	medium	-	90	Projectile	105mm
72	4309680.8	641432.8	0.213	Ordnance	Low	large	-	0	Rocket	2.75in

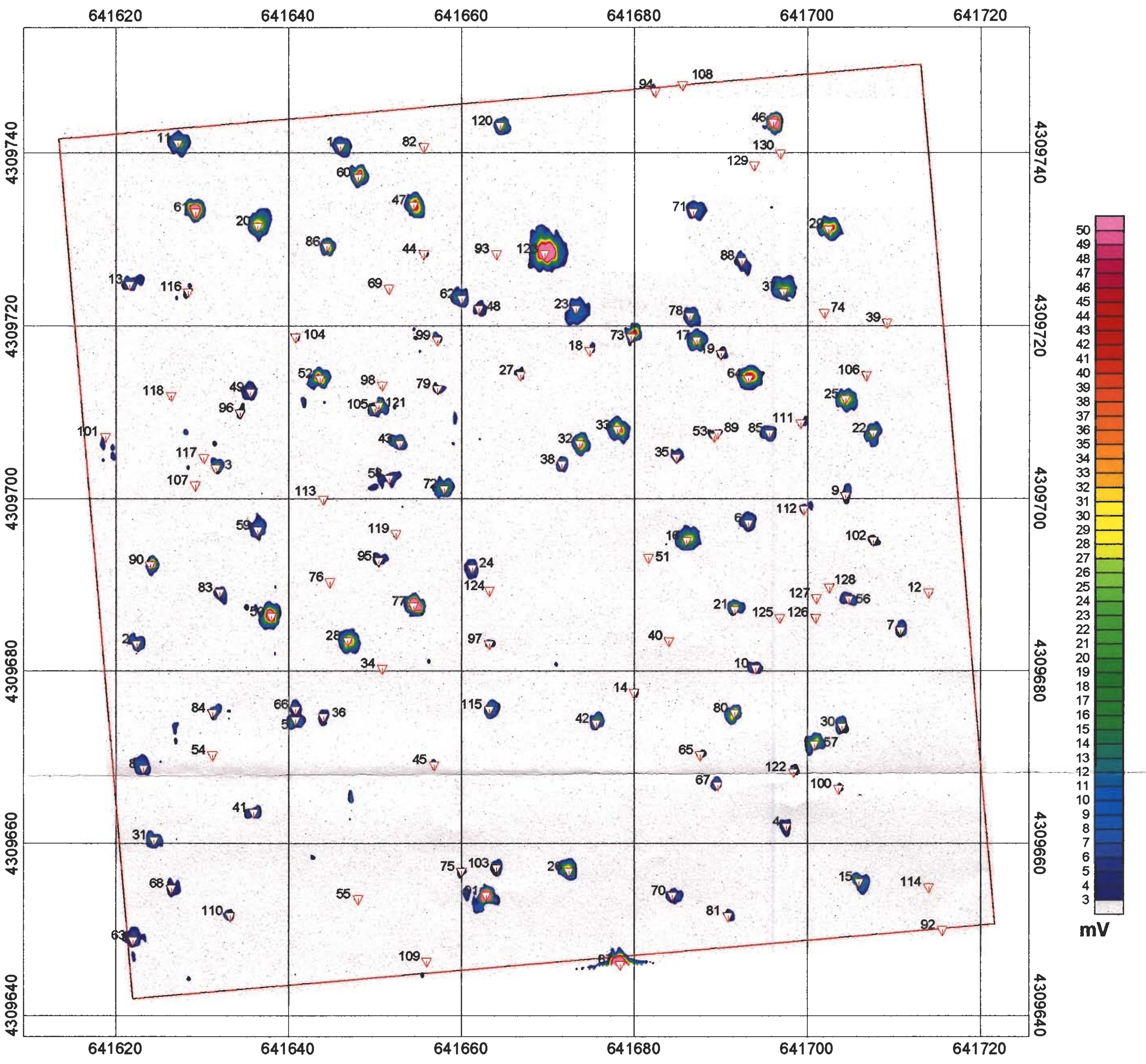
DIG LIST: 1 Demonstrator: NAEVA Test Area: 1 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
73	4309665.2	641362.8	0	Ordnance	Low	small	-	0	Mortar	60mm
74	4309699.6	641384	0	Ordnance	Low	small	-	0	Mortar	60mm
75	4309665.2	641367.6	0.287	Ordnance	Low	large	-	0	Mortar	81mm
76	4309654.8	641378	0.121	Ordnance	Low	small	-	0	Rocket	2.75in
77	4309650.4	641357.6	0.0108	Ordnance	Low	small	-	0	Projectile	20mm
78	4309636.4	641436.4	0.39	Ordnance	Low	medium	-	0	Mortar	81mm
79	4309614.8	641410.4	0.132	Ordnance	Low	small	-	0	Projectile	20mm
80	4309624.4	641348.8	0.332	Ordnance	Low	small	-	0	Projectile	57mm
81	4309648.8	641387.2	0.0116	Clutter	Low	medium	-	-	-	-
82	4309677.2	641376	0	Clutter	Low	small	-	-	-	-
83	4309690.4	641358.4	0	Clutter	Low	small	-	-	-	-
84	4309638.4	641360.4	0.144	Clutter	Low	medium	-	-	-	-
85	4309661.2	641386	0.319	Clutter	Low	medium	-	-	-	-
86	4309618.8	641435.2	0.341	Clutter	Low	medium	-	-	-	-
87	4309605.92	641392.81	0	Clutter	Low	small	-	-	-	-
88	4309609.6	641417.6	0.341	Clutter	Low	medium	-	-	-	-
89	4309686	641353.6	0.0745	Clutter	Low	small	-	-	-	-
90	4309651.2	641345.6	0.0141	Clutter	Low	medium	-	-	-	-
91	4309654	641380	0.342	Clutter	Low	large	-	-	-	-
92	4309610	641344.8	0.154	Clutter	Low	medium	-	-	-	-
93	4309684	641361.6	0	Clutter	Low	small	-	-	-	-
94	4309651.6	641361.2	0	Clutter	Low	small	-	-	-	-
95	4309670.4	641403.6	0.291	Clutter	Low	large	-	-	-	-
96	4309653.6	641438	0.151	Clutter	Low	large	-	-	-	-
97	4309616.8	641360.4	0.451	Clutter	Low	medium	-	-	-	-
98	4309705.6	641410.8	0.227	Clutter	Low	medium	-	-	-	-
99	4309634	641400.8	0.435	Clutter	Low	medium	-	-	-	-
100	4309662.4	641378.8	0.131	Clutter	Low	medium	-	-	-	-
101	4309620.8	641369.6	0.483	Clutter	Low	large	-	-	-	-
102	4309628.8	641425.2	0	Clutter	Low	small	-	-	-	-
103	4309632	641341.2	0.487	Clutter	High	medium	-	-	-	-
104	4309701.2	641424	0.0909	Clutter	High	medium	-	-	-	-
105	4309671.6	641380.8	0.438	Clutter	High	large	-	-	-	-
106	4309643.6	641435.2	0.777	Clutter	High	large	-	-	-	-
107	4309621.6	641367.2	0	Clutter	High	small	-	-	-	-
108	4309643.2	641340.8	0	Clutter	High	small	-	-	-	-

DIG LIST: 1 Demonstrator: NAEVA Test Area: 1 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
109	4309680	641345.2	0.0605	Clutter	High	medium	-	-	-	-
110	4309666	641417.6	0	Clutter	High	small	-	-	-	-
111	4309677.6	641413.6	0.0017	Clutter	High	medium	-	-	-	-
112	4309653.6	641362.8	0	Clutter	High	small	-	-	-	-
113	4309643.08	641339.54	0	Clutter	High	small	-	-	-	-
114	4309640.4	641362.8	0.318	Clutter	High	medium	-	-	-	-
115	4309620.8	641438	0.193	Clutter	High	large	-	-	-	-
116	4309678.8	641367.6	0.153	Clutter	High	medium	-	-	-	-
117	4309635.2	641374.4	0.27	Clutter	High	medium	-	-	-	-
118	4309629.6	641413.2	0	Clutter	High	small	-	-	-	-
119	4309622	641403.2	0.0214	Clutter	High	small	-	-	-	-
120	4309702.4	641358.4	0	Clutter	High	small	-	-	-	-
121	4309663.6	641372.4	0.246	Clutter	High	medium	-	-	-	-
122	4309635.2	641425.6	0.119	Clutter	High	medium	-	-	-	-
123	4309659.6	641392.8	0.124	Clutter	High	small	-	-	-	-
124	4309642.488	641344.424	0.5	Clutter	High	medium	-	-	-	-
125	4309640.57	641365.453	0.5	Clutter	High	medium	-	-	-	-
126	4309651.074	641379.612	0.5	Clutter	High	medium	-	-	-	-
127	4309646.131	641434.181	0.5	Clutter	High	medium	-	-	-	-
28	4309660.349	641423.228	0.5	Clutter	High	medium	-	-	-	-

Appendix B: Grid 2 Target List and Contour Map



Legend

Grid 2 Boundary

2 Selected Target
(See Prioritized Target List For Response and Location)

Scale 1:550

10 0 10

metre

NAEVA GEOPHYSICS INC.
SUBSURFACE GEOPHYSICAL SURVEYS

Advanced UXO Detection/Discrimination Technology Demonstration

EM-63 Prioritized Targets
Grid 2 - Gate 10
U.S. Army Jefferson Proving Grounds
Madison, Indiana

Dates of Survey: September 11-18, 2000

DIG LIST: 2 Demonstrator: NAEVA Test Area: 2 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
1	4309740.8	641646	0.261	Ordnance	High	medium	-	0	Projectile	76mm
2	4309683.2	641622.4	0	Ordnance	High	small	-	0	Mortar	60mm
3	4309703.6	641631.6	0.182	Ordnance	High	medium	-	0	Mortar	4.2in
4	4309662	641697.6	0.141	Ordnance	High	small	-	0	Mortar	60mm
5	4309674.4	641640.8	0.189	Ordnance	High	medium	-	0	Rocket	2.75in
6	4309697.2	641693.2	0.684	Ordnance	High	large	-	0	Projectile	152mm
7	4309684.8	641710.8	0.0395	Ordnance	High	small	-	0	Mortar	4.2in
8	4309668.8	641623.2	0.417	Ordnance	High	large	-	0	Mortar	81mm
9	4309700.4	641704.4	0.35	Ordnance	High	medium	-	17.7	Projectile	5in
10	4309680.4	641694	0.0624	Ordnance	High	small	-	0	Rocket	2.75in
11	4309741.2	641627.2	0.686	Ordnance	High	large	-	57.3	Projectile	155mm
12	4309689.2	641714	0.749	Ordnance	High	medium	-	0	Projectile	20mm
13	4309724.8	641621.6	0.408	Ordnance	High	large	-	0	Rocket	2.75in
14	4309677.6	641680	0.415	Ordnance	High	medium	-	0	Projectile	76mm
15	4309655.6	641706	0	Ordnance	High	small	-	0	Mortar	60mm
16	4309695.2	641686	0.393	Ordnance	High	large	-	0	Projectile	152mm
17	4309718.4	641687.2	0.382	Ordnance	High	large	-	0	Projectile	152mm
18	4309717.2	641674.8	0.256	Ordnance	High	small	-	0	Projectile	155mm
19	4309716.8	641690	0.0841	Ordnance	High	small	-	0	Projectile	57mm
20	4309731.6	641636.4	0.438	Ordnance	High	large	-	0	Mortar	81mm
21	4309687.2	641691.6	0.215	Ordnance	High	medium	-	0	Mortar	81mm
22	4309707.6	641707.6	0.135	Ordnance	High	medium	-	0	Mortar	81mm
23	4309722	641673.2	0.572	Ordnance	High	large	-	0	Mortar	4.2in
24	4309692	641661.2	0.465	Ordnance	High	large	-	0	Mortar	81mm
25	4309711.6	641704.4	0.289	Ordnance	High	large	-	0	Projectile	57mm
26	4309656.8	641672.4	0.294	Ordnance	High	large	-	0	Projectile	152mm
27	4309714.4	641666.8	0.0473	Ordnance	High	small	-	0	Mortar	60mm
28	4309683.6	641646.8	0.353	Ordnance	High	large	-	0	Projectile	152mm
29	4309731.2	641702.4	0.317	Ordnance	High	large	-	0	Mortar	4.2in
30	4309673.6	641704	0	Ordnance	High	small	-	0	Projectile	152mm
31	4309660.4	641624.4	0.262	Ordnance	High	medium	-	0	Mortar	60mm
32	4309706.4	641673.6	0.228	Ordnance	High	large	-	0	Mortar	81mm
33	4309708	641678	0.407	Ordnance	High	large	-	0	Mortar	81mm
34	4309680.4	641650.8	0.47	Ordnance	High	medium	-	0	Projectile	57mm
35	4309704.8	641684.8	0.65	Ordnance	High	large	-	77.2	Projectile	105mm
36	4309674.8	641644	0.61	Ordnance	High	medium	-	0	Mortar	81mm

DIG LIST: 2 Demonstrator: NAEVA Test Area: 2 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
37	4309724	641697.2	0.36	Ordnance	High	large	-	0	Projectile	57mm
38	4309704	641671.6	0	Ordnance	High	small	-	0	Projectile	105mm
39	4309720.4	641709.2	0	Ordnance	High	small	-	0	Projectile	20mm
40	4309683.6	641684	0.814	Ordnance	High	large	-	76	Projectile	105mm
41	4309663.6	641636	0.0631	Ordnance	High	medium	-	0	Projectile	152mm
42	4309674	641675.6	0.437	Ordnance	High	large	-	0	Projectile	76mm
43	4309706.4	641652.8	0.19	Ordnance	High	medium	-	0	Mortar	81mm
44	4309728.4	641655.6	0.158	Ordnance	High	large	-	40	Projectile	5in
45	4309669.2	641656.8	0	Ordnance	High	small	-	0	Projectile	20mm
46	4309743.6	641696	0.228	Ordnance	High	large	-	0	Projectile	155mm
47	4309734	641654.4	0.284	Ordnance	High	large	-	0	Mortar	81mm
48	4309722	641662	0.527	Ordnance	High	medium	-	0	Mortar	60mm
49	4309712.4	641635.6	0.843	Ordnance	High	large	-	0	Mortar	4.2in
50	4309686.4	641638	0.506	Ordnance	High	large	-	10.7	Projectile	155mm
51	4309693.2	641681.6	0.278	Ordnance	High	small	-	0	Projectile	105mm
52	4309714	641643.6	0.115	Ordnance	High	medium	-	0	Rocket	2.75in
53	4309707.2	641689.2	0.741	Ordnance	High	large	-	0	Projectile	105mm
54	4309670.4	641631.2	0.3	Ordnance	High	small	-	0	Projectile	57mm
55	4309653.6	641648	0	Ordnance	High	small	-	0	Projectile	20mm
56	4309688.4	641704.8	0.0922	Ordnance	High	small	-	0	Projectile	20mm
57	4309671.6	641700.8	0.169	Ordnance	High	medium	-	0	Mortar	60mm
58	4309702.4	641651.6	0.312	Ordnance	High	medium	-	90	Projectile	5in
59	4309696.4	641636.4	0.229	Ordnance	High	medium	-	0	Mortar	81mm
60	4309737.2	641648	0.144	Ordnance	Low	medium	-	0	Mortar	4.2in
61	4309733.2	641629.2	0.112	Ordnance	Low	large	-	0	Projectile	5in
62	4309723.2	641660	0.0421	Ordnance	Low	small	-	38	Projectile	5in
63	4309648.8	641622	1.03	Ordnance	Low	large	-	0	Projectile	20mm
64	4309714	641693.2	0.476	Ordnance	Low	large	-	0	Mortar	81mm
65	4309670.4	641687.6	0.286	Ordnance	Low	medium	-	0	Mortar	60mm
66	4309675.6	641640.8	0.401	Ordnance	Low	medium	-	0	Projectile	20mm
67	4309666.8	641689.6	0.0988	Ordnance	Low	medium	-	0	Mortar	60mm
68	4309654.8	641626.4	1.5	Ordnance	Low	large	-	90	Projectile	155mm
69	4309724.4	641651.6	0.114	Ordnance	Low	medium	-	0	Mortar	81mm
70	4309654	641684.4	0.269	Ordnance	Low	medium	-	0	Mortar	60mm
71	4309733.2	641686.8	0.681	Ordnance	Low	large	-	0	Projectile	105mm
72	4309701.2	641658	0.418	Ordnance	Low	large	-	0	Projectile	5in

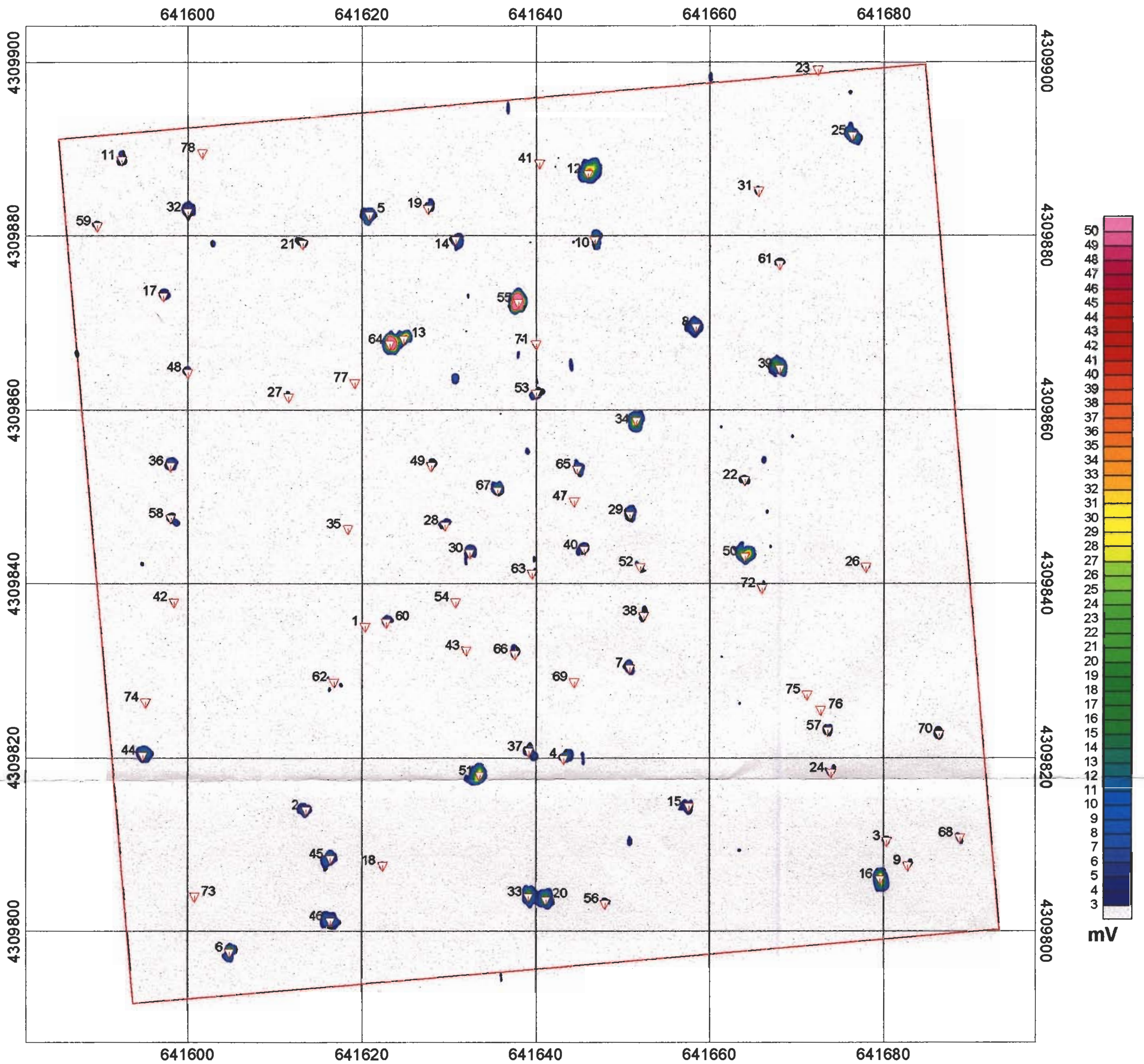
DIG LIST: 2 Demonstrator: NAEVA Test Area: 2 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
73	4309718.8	641679.6	0.258	Ordnance	Low	large	-	0	Projectile	152mm
74	4309721.6	641702	0	Ordnance	Low	small	-	0	Projectile	20mm
75	4309656.8	641660	0.309	Ordnance	Low	medium	-	0	Projectile	20mm
76	4309690.4	641644.8	0.948	Ordnance	Low	large	-	90	Projectile	105mm
77	4309687.6	641654.4	0.0387	Ordnance	Low	medium	-	0	Projectile	152mm
78	4309721.2	641686.4	0.335	Ordnance	Low	medium	-	0	Mortar	81mm
79	4309712.8	641657.2	0	Clutter	Low	small	-	-	-	-
80	4309675.2	641691.6	0.0248	Clutter	Low	medium	-	-	-	-
81	4309651.6	641690.8	0.735	Clutter	Low	large	-	-	-	-
82	4309740.8	641655.6	0.182	Clutter	Low	small	-	-	-	-
83	4309689.2	641632	0.486	Clutter	Low	large	-	-	-	-
84	4309675.2	641631.2	0.0796	Clutter	Low	medium	-	-	-	-
85	4309707.6	641695.6	0.215	Clutter	Low	medium	-	-	-	-
86	4309729.2	641644.4	0.132	Clutter	Low	medium	-	-	-	-
87	4309646	641678.3	0.0963	Clutter	Low	large	-	-	-	-
88	4309727.6	641692.4	0.156	Clutter	Low	medium	-	-	-	-
89	4309707.6	641689.6	0.0612	Clutter	Low	small	-	-	-	-
90	4309692.4	641624	0.0727	Clutter	Low	medium	-	-	-	-
91	4309654	641662.8	0.00522	Clutter	Low	large	-	-	-	-
92	4309650	641715.6	1.8	Clutter	Low	large	-	-	-	-
93	4309728.4	641664	0.267	Clutter	Low	small	-	-	-	-
94	4309747.2	641682.4	0	Clutter	Low	small	-	-	-	-
95	4309692.8	641650.4	0	Clutter	Low	small	-	-	-	-
96	4309710	641634.4	1.34	Clutter	Low	large	-	-	-	-
97	4309683.2	641663.2	0.07	Clutter	Low	small	-	-	-	-
98	4309713.2	641650.8	0	Clutter	Low	small	-	-	-	-
99	4309718.4	641657.2	0.517	Clutter	Low	medium	-	-	-	-
100	4309666.4	641703.6	0.0207	Clutter	Low	small	-	-	-	-
101	4309707.2	641618.8	0.521	Clutter	Low	medium	-	-	-	-
102	4309695.2	641707.6	0	Clutter	Low	small	-	-	-	-
103	4309657.2	641664	0	Clutter	Low	small	-	-	-	-
104	4309718.8	641640.8	0	Clutter	Low	small	-	-	-	-
105	4309710.4	641650	0.2	Clutter	Low	medium	-	-	-	-
106	4309714.4	641706.8	2	Clutter	High	medium	-	-	-	-
107	4309701.6	641629.2	0	Clutter	High	small	-	-	-	-
108	4309748	641685.6	0	Clutter	High	small	-	-	-	-

DIG LIST: 2 Demonstrator: NAEVA Test Area: 2 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
109	4309646.4	641656	0	Clutter	High	small	-	-	-	-
110	4309651.6	641633.2	0.0676	Clutter	High	medium	-	-	-	-
111	4309708.8	641699.2	0	Clutter	High	small	-	-	-	-
112	4309698.8	641699.6	0	Clutter	High	small	-	-	-	-
113	4309700	641644	0	Clutter	High	small	-	-	-	-
114	4309655	641714	2	Clutter	High	large	-	-	-	-
115	4309675.6	641663.2	0.0183	Clutter	High	small	-	-	-	-
116	4309724	641628.4	0	Clutter	High	small	-	-	-	-
117	4309704.73	641630.18	1	Clutter	High	small	-	-	-	-
118	4309712	641626.4	0	Clutter	High	small	-	-	-	-
119	4309696	641652.4	0	Clutter	High	small	-	-	-	-
120	4309743.2	641664.4	0.0937	Clutter	High	medium	-	-	-	-
121	4309710.8	641650.4	0.1	Clutter	High	medium	-	-	-	-
122	4309668.4	641698.4	0.153	Clutter	High	medium	-	-	-	-
123	4309728.4	641669.6	0.696	Clutter	High	large	-	-	-	-
124	4309689.398	641663.228	0.5	Clutter	High	medium	-	-	-	-
125	4309686.283	641696.81	0.5	Clutter	High	medium	-	-	-	-
126	4309686.264	641700.925	0.5	Clutter	High	medium	-	-	-	-
127	4309688.533	641701.047	0.5	Clutter	High	medium	-	-	-	-
128	4309689.813	641702.516	0.5	Clutter	High	medium	-	-	-	-
129	4309738.613	641693.853	0.5	Clutter	High	medium	-	-	-	-
130	4309739.993	641696.867	0.5	Clutter	High	medium	-	-	-	-

Appendix C: Grid 3 Target List and Contour Map



Scale 1:550

10 0 10

metre

Legend

Grid 3 Boundary

Selected Target
(See Prioritized Target List For Response and Location)

NAEVA GEOPHYSICS INC.
SUBSURFACE GEOPHYSICAL SURVEYS

Advanced UXO Detection/Discrimination Technology Demonstration

EM-63 Prioritized Targets
Grid 3 - Gate 10
U.S. Army Jefferson Proving Grounds
Madison, Indiana

Dates of Survey: September 11-18, 2000

DIG LIST: 3 Demonstrator: NAEVA Test Area: 3 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
1	4309835.20	641620.40	0.237	Ordnance	High	small	-	0	Mortar	4.2in
2	4309814.00	641613.60	0.150	Ordnance	High	small	-	0	Mortar	60mm
3	4309810.40	641680.40	0.415	Ordnance	High	medium	-	0	Projectile	5in
4	4309820.00	641643.20	0.143	Ordnance	High	medium	-	0	Projectile	152mm
5	4309882.40	641620.80	0.000	Ordnance	High	small	-	0	Rocket	2.75in
6	4309797.60	641604.80	0.000	Ordnance	High	small	-	0	Mortar	60mm
7	4309830.40	641650.80	0.236	Ordnance	High	medium	-	0	Mortar	81mm
8	4309869.60	641658.40	0.631	Ordnance	High	large	-	0	Projectile	152mm
9	4309807.60	641682.80	0.092	Ordnance	High	small	-	0	Projectile	57mm
10	4309879.60	641646.80	0.000	Ordnance	High	small	-	0	Projectile	152mm
11	4309888.80	641592.40	0.000	Ordnance	High	small	-	0	Projectile	76mm
12	4309887.20	641646.00	0.357	Ordnance	High	large	-	0	Projectile	152mm
13	4309868.20	641624.80	0.220	Ordnance	High	large	-	0	Projectile	152mm
14	4309879.60	641630.80	0.164	Ordnance	High	medium	-	0	Projectile	155mm
15	4309814.40	641657.60	0.368	Ordnance	High	medium	-	0	Mortar	81mm
16	4309806.00	641679.60	0.173	Ordnance	High	medium	-	0	Projectile	76mm
17	4309873.20	641597.20	0.429	Ordnance	High	medium	-	0	Projectile	105mm
18	4309807.60	641622.40	0.216	Ordnance	High	medium	-	0	Mortar	60mm
19	4309883.20	641627.60	0.130	Ordnance	High	small	-	0	Rocket	2.75in
20	4309803.60	641641.20	0.133	Ordnance	High	medium	-	0	Mortar	60mm
21	4309879.20	641613.20	0.026	Ordnance	High	small	-	0	Rocket	2.75in
22	4309852.00	641664.00	0.275	Ordnance	High	medium	-	0	Projectile	105mm
23	4309899.20	641672.40	0.519	Ordnance	High	medium	-	0	Mortar	81mm
24	4309818.40	641674.00	0.000	Ordnance	High	small	-	0	Mortar	81mm
25	4309891.60	641676.40	0.093	Ordnance	High	medium	-	0	Mortar	81mm
26	4309842.00	641678.00	0.263	Ordnance	High	medium	-	0	Projectile	20mm
27	4309861.60	641611.60	0.663	Ordnance	High	large	-	90	Projectile	155mm
28	4309846.80	641629.60	0.297	Ordnance	High	small	-	0	Mortar	81mm
29	4309848.00	641650.80	0.241	Ordnance	High	medium	-	0	Projectile	152mm
30	4309843.60	641632.40	0.265	Ordnance	High	medium	-	0	Projectile	152mm
31	4309885.20	641665.60	0.075	Ordnance	High	small	-	0	Projectile	20mm
32	4309882.80	641600.00	1.330	Ordnance	High	large	-	8.07	Projectile	5in
33	4309804.00	641639.20	0.000	Ordnance	High	small	-	0	Projectile	152mm
34	4309858.80	641651.60	0.268	Ordnance	High	large	-	0	Mortar	81mm
35	4309846.40	641618.40	0.428	Ordnance	High	medium	-	0	Projectile	20mm
36	4309853.60	641598.00	0.493	Ordnance	High	medium	-	0	Rocket	2.75in

DIG LIST: 3 Demonstrator: NAEVA Test Area: 3 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
37	4309820.80	641639.20	0.084	Ordnance	High	small	-	0	Mortar	81mm
38	4309836.40	641652.40	0.008	Ordnance	High	small	-	0	Projectile	20mm
39	4309864.80	641668.00	0.246	Ordnance	High	medium	-	0	Mortar	4.2in
40	4309844.00	641645.60	0.374	Ordnance	High	medium	-	0	Rocket	2.75in
41	4309888.40	641640.40	0.317	Ordnance	High	small	-	90	Projectile	105mm
42	4309838.00	641598.40	0.000	Ordnance	High	small	-	0	Mortar	81mm
43	4309832.40	641632.00	0.656	Ordnance	High	large	-	90	Projectile	105mm
44	4309820.40	641594.80	0.126	Ordnance	Low	medium	-	0	Mortar	60mm
45	4309808.40	641616.40	0.047	Ordnance	Low	medium	-	0	Mortar	60mm
46	4309801.20	641616.40	0.587	Ordnance	Low	large	-	0	Mortar	81mm
47	4309849.60	641644.40	0.000	Ordnance	Low	small	-	0	Projectile	20mm
48	4309864.40	641600.00	0.126	Ordnance	Low	small	-	0	Rocket	2.75in
49	4309853.60	641628.00	0.000	Ordnance	Low	small	-	0	Rocket	2.75in
50	4309843.20	641664.00	0.195	Ordnance	Low	medium	-	0	Mortar	81mm
51	4309818.00	641633.60	0.210	Ordnance	Low	medium	-	0	Mortar	81mm
52	4309842.00	641652.00	0.747	Ordnance	Low	large	-	0	Mortar	81mm
53	4309862.00	641640.00	0.166	Ordnance	Low	small	-	0	Mortar	81mm
54	4309838.00	641630.80	0.270	Ordnance	Low	small	-	0	Mortar	60mm
55	4309872.40	641638.00	0.000	Ordnance	Low	medium	-	0	Projectile	57mm
56	4309803.20	641648.00	0.000	Ordnance	Low	small	-	0	Projectile	20mm
57	4309823.20	641673.60	0.000	Ordnance	Low	small	-	0	Projectile	20mm
58	4309847.60	641598.00	0.001	Clutter	Low	small	-	-	-	-
59	4309881.20	641589.60	0.082	Clutter	Low	small	-	-	-	-
60	4309835.60	641622.80	0.000	Clutter	Low	small	-	-	-	-
61	4309876.80	641668.00	0.000	Clutter	Low	small	-	-	-	-
62	4309828.80	641616.80	0.595	Clutter	Low	medium	-	-	-	-
63	4309841.20	641639.60	1.110	Clutter	Low	large	-	-	-	-
64	4309867.60	641623.20	0.043	Clutter	Low	medium	-	-	-	-
65	4309853.20	641644.80	0.253	Clutter	Low	medium	-	-	-	-
66	4309832.00	641637.60	0.415	Clutter	High	medium	-	-	-	-
67	4309850.80	641635.60	0.154	Clutter	High	medium	-	-	-	-
68	4309810.80	641688.80	0.282	Clutter	High	small	-	-	-	-
69	4309828.80	641644.40	0.000	Clutter	High	small	-	-	-	-
70	4309822.80	641686.40	0.043	Clutter	High	small	-	-	-	-
71	4309867.60	641640.00	2.000	Clutter	High	large	-	-	-	-
72	4309839.60	641666.00	2.000	Clutter	High	small	-	-	-	-

DIG LIST: 3 Demonstrator: NAEVA Test Area: 3 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
73	4309804.05	641600.83	0.500	Clutter	High	medium	-	-	-	-
74	4309826.49	641595.14	0.500	Clutter	High	medium	-	-	-	-
75	4309827.38	641671.18	0.500	Clutter	High	medium	-	-	-	-
76	4309825.60	641672.78	0.500	Clutter	High	medium	-	-	-	-
77	4309863.22	641619.19	0.500	Clutter	High	medium	-	-	-	-
78	4309889.64	641601.61	0.500	Clutter	High	medium	-	-	-	-

DIG LIST: 3 Demonstrator: NAEVA Test Area: 3 Including 20mm: Yes

#	Northing	Easting	Depth	Type	Confidence	Size	Azimuth	Incl	Class	Type
73	4309804.05	641600.83	0.500	Clutter	High	medium	-	-	-	-
74	4309826.49	641595.14	0.500	Clutter	High	medium	-	-	-	-
75	4309827.38	641671.18	0.500	Clutter	High	medium	-	-	-	-
76	4309825.60	641672.78	0.500	Clutter	High	medium	-	-	-	-
77	4309863.22	641619.19	0.500	Clutter	High	medium	-	-	-	-
78	4309889.64	641601.61	0.500	Clutter	High	medium	-	-	-	-

Appendix D: CD Containing Data and Software

Final Report
Data Files
Prioritized Target Lists
Geosoft Maps (.map) and Image Files (.bmp) for Grids 1, 2 and 3
Executable Software to Intergrate GPS and EM-63 Raw Data
Matlab Scripts to Perform Chi–Squared Fit Computation

Appendix E: Points of Contact

Prime Contractor:

NAEVA Geophysics
P.O. Box 7325
Charlottesville, VA 22906
Phone: (804) 978-3187
Fax: (804) 973-9791
e-mail: jallan@naevageophysics.com
Point of Contact: John Allan

Subcontractor:

Geophysical Associates (GPA)
P.O. Box 153
Ivy, VA 22945
Phone: (804) 293-6737
e-mail: hware@naevageophysics.com
Point of Contact: G. Hunter Ware

NAEVA Geophysics contracted geophysical Associates for advanced data processing and algorithm development.

Appendix F: Data and Demonstration Plan

Data: All data has been submitted to ESTCP in digital format. A description of the data processing procedures has been included herewith in the report in section 3.

Demonstration Plan: Previously submitted to Ernie Cespedes and is available through ESTCP.